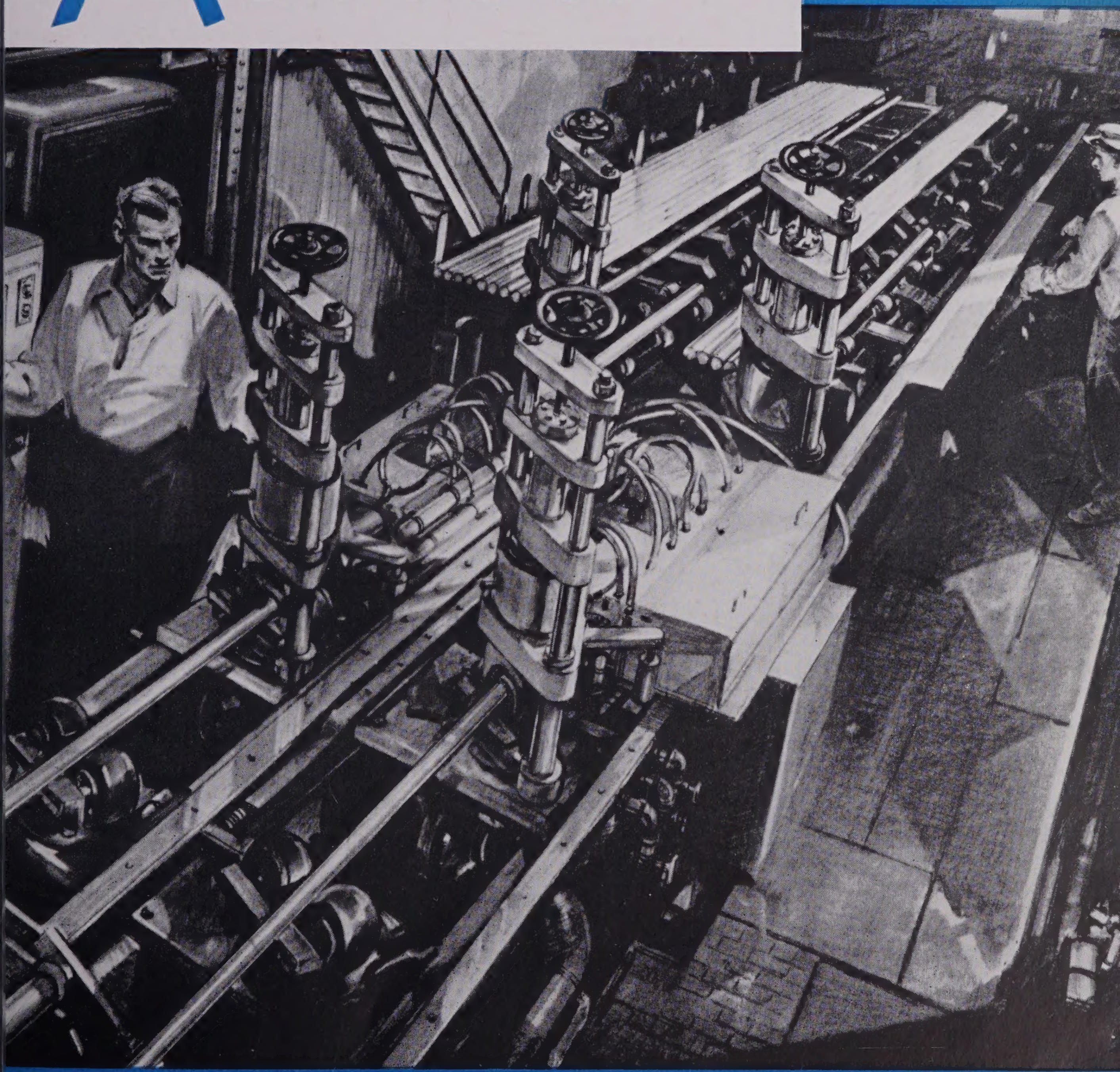
UME 51 NUMBER 2 . . . . ONE YEAR THREE FIFTY

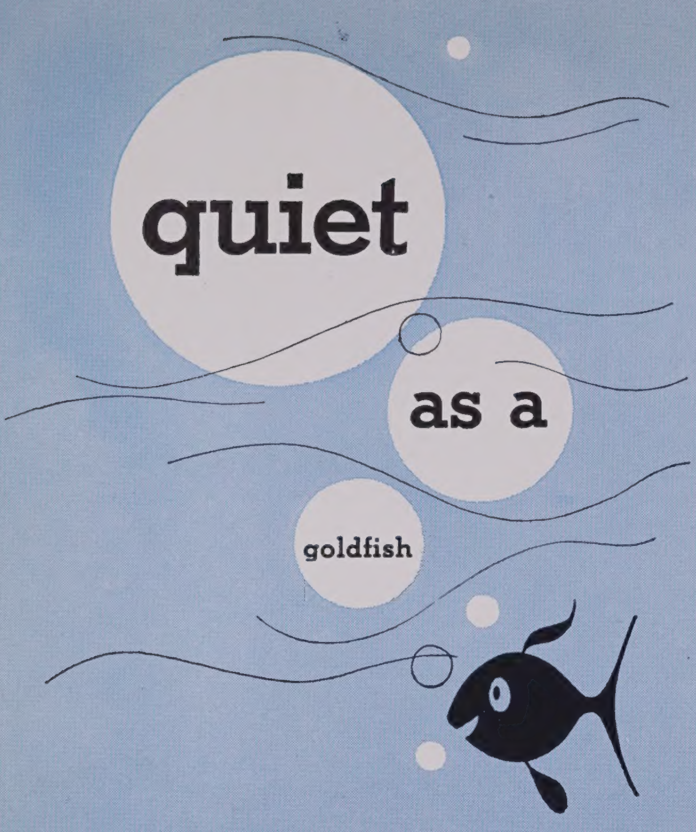
Illinois U Library

GENERAL ELECTRIC Review

TABLE OF CONTENTS
Page Three



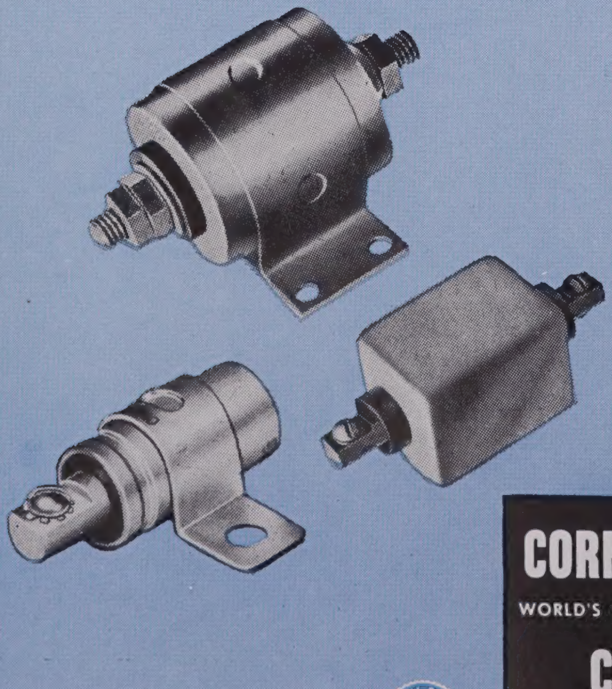
February, 1948



with **C-D Quietones***

A lot of *electronic and electrical equipment is going to sea these days. But it won't stay there long—in fact, it won't even stay sold—unless it is Noise-Proofed against radio interference.*

To you—the manufacturer—this means that your product should include C-D Quietones in its basic design. With safety at sea—as well as listening pleasure—at stake, your marine customers demand the kind of interference-free equipment operation C-D Quietones are designed to give. Of the hundreds of Quietone types available, there may be one which will fit your needs to a "T"; if not, our sleeves are rolled up and we're ready in our modern and complete Radio Noise-Proofing Laboratory—to design the specific filter you need. C-D Quietones will solve your radio noise and spark suppression problems speedily, permanently and effectively. Your inquiry is invited. Cornell-Dubilier Electric Corporation, Dept. L2, South Plainfield, New Jersey. Other large plants in New Bedford, Worcester, and Brookline, Massachusetts, and Providence, R. I.



Make Your Products More Saleable with C-D Quietone Radio Noise Filters and Spark Suppressors.

An Invitation from C-D
WORLD'S MOST ADVANCED RADIO "NOISE-PROOFING" LABORATORY IS AT YOUR SERVICE
without obligation

CORNELL-DUBILIER
WORLD'S LARGEST MANUFACTURER OF
CAPACITORS

MICA • DYKANOL • PAPER • ELECTROLYTIC

* Reg. U.S. Pat. Off.

GENERAL ELECTRIC Review

FEBRUARY, 1948
Vol. 51, No. 2

R. S. PEARE
Manager

E. C. SANDERS
Executive Editor

J. E. GLICK
Associate Editor

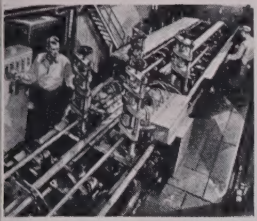


Photo courtesy of Jones & Laughlin

THE COVER

A modern method of rapidly and economically heat-treating conductive materials is by the use of induction heating. In this method, the lateral surface of the charge is exposed to an alternating magnetic flux, the frequency of which is one of the determining factors in the effectiveness with which the material can be heated. In this illustration is shown a large-scale application of induction heating with 9600 cycles for the continuous heat-treatment of cold-rolled steel bars. See "Induction Heating Applications," page 44.

ADVERTISING INDEX

Aluminum Company of America 6
American Brass Co. 1
American Lava Corp. 8
Anaconda Copper Mining Co. 1

Brand & Co., Wm. 7
British Thomson-Houston Co., Ltd. 55, 60

Canadian General Electric Co., Ltd. 57
Clare and Co., C. P. 4
Clarostat Manufacturing Co., Inc. 50
Cornell-Dubilier Electric Corp. . . . . . 2nd cover

Driver-Harris Co. 63

Edison-Swan Electric Co., Ltd. 60

Ferguson, Pailin Ltd. 60

General Electric Co. . . . . . 42, 59, 62, 3rd cover
Giannini, G. M. 61

Harcourts, Ltd. 60
Hotpoint Electric Appliance Co., Ltd. 60

Ilsco Copper Tube & Products, Inc. 50
Ingersoll-Rand Co. 64

Mallory, P. R. & Co., Inc. 53
Metropolitan-Vickers Electrical Co., Ltd. 60
Metropolitan-Vickers-G. R. S. Ltd. 60
Miniature Precision Bearings 25

National Carbon Co., Inc. 2
New Departure-Div. General Motors Corp. 26

O. Z. Electrical Manufacturing Co. 9

Phillips Control Corp. 51

Roll-A-Reel 58

Sexton Can Co., Inc. 50
Sherron Electronics Co. 27
SKF Industries, Inc. 21
Sola Electric Co. . . . . . 4th cover
Speer Carbon Co. 20

Ward Leonard Electric Co. 25
West Virginia Pulp & Paper Co. 57

EDITORIAL CONTENTS

FRONTISPIECE: For Wind-tunnel Research 10

ARTICLES:

A-c Power System for Large Aircraft . Dr. John G. Hutton 11
Developmental two-generator system holds promise of meeting new requirements that have been imposed by increased power demands and by higher altitudes of flight.

High-voltage Rectifier Circuits: Part I . . . E. V. DeBlieux 22
Circuit, transformer, and tube characteristics that determine the type of circuit preferred. Filament-transformer economy and filter requirements

Speed-control Systems for High-speed Squirrel-cage Motors . . . G. W. Heumann 28
All utilize the principle of converting the frequency of the power supply to values above that of the commercial source

Gaseous Insulation for High-voltage Apparatus . . . G. Camilli and J. J. Chapman 35
Investigations reveal that sulphur hexafluoride possesses superior insulating qualities, even at the low pressures of one, two, and three atmospheres

Induction Heating Applications . . . . N. R. Stansel 44
At all temperatures, flux distribution, eddy currents, and electrical efficiency related through mathematical formulas. How they apply to temperatures below melting point

DEPARTMENTS:

High Lights and Side Lights . 52
New Products . . . 54
Trade Literature . 57
Book Reviews . 58
Library Notes . 61

INDEXED BY INDUSTRIAL ARTS INDEX, ENGINEERING INDEX, SCIENCE ABSTRACTS

Editorial Advisory Board: H. A. WINNE, Chairman • H. L. ANDREWS
Dr. W. R. G. BAKER • Dr. WARD HARRISON • Dr. R. C. MUIR

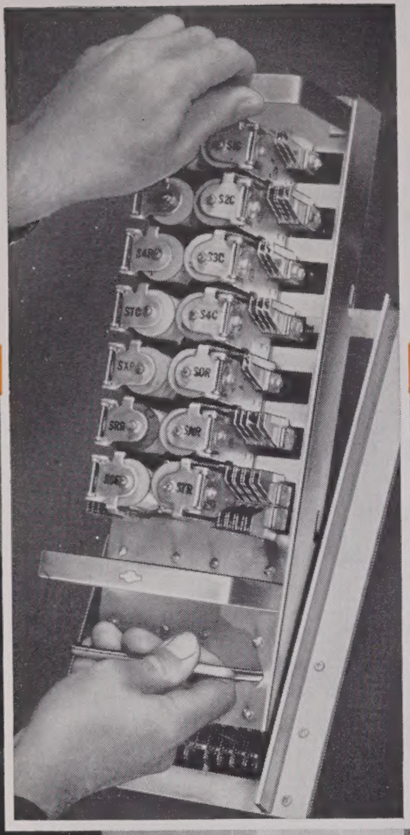
CIRCULATION DEPARTMENT: General Electric Review, Schenectady 5, New York. Great Britain: General Electric Review, Crown House, Aldwych, London, W. C. 2, England.

SUBSCRIPTION RATES: *Payable in advance.* United States and Possessions, and countries in Pan-American Union, one year $3.50, two years $5.50. Canada, one year $3.75, two years $5.75. Other foreign countries, $4.00 a year, $6.00 two years. Public and college libraries, professors, and enrolled students deduct $1.00 from annual rates. SINGLE COPY 35¢.

CHANGE OF ADDRESS: Give old and new addresses. Notices received before the fifteenth of the month will be effective with the next issue.

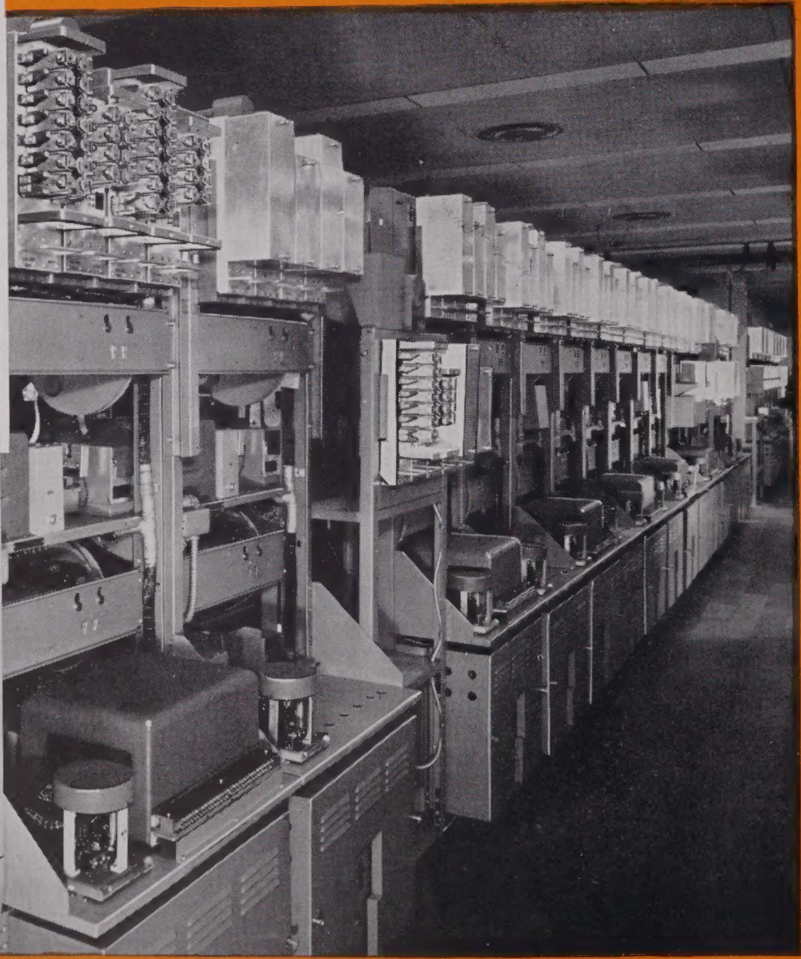
ADVERTISING DEPARTMENT: General Electric Review, Schenectady 5, New York.

Entered as second-class matter, March 26, 1912, at the post office at Schenectady, N. Y., under Act of March 3, 1879. Published monthly by General Electric Company, 1 River Road, Schenectady 5, N. Y. Printed in U. S. A. *Copyright 1948 by General Electric Company.*



WESTERN UNION

in Sensationally Rapid



Hundreds of Clare Relays are used in this Western Union Push-Button Switching installation. Covers are removed from first four banks at top to show location of Clare Relays, which play an important part in Western Union's new ultra-modern, high-speed communications program. Pictured is a rear view of positions on which the outgoing sides of the various circuits are terminated.

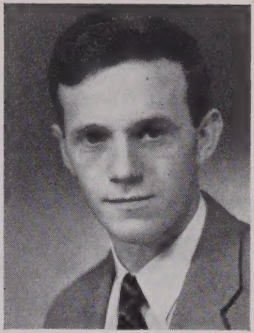
Picture in upper left shows the easily removable Clare mounting base used in this Western Union installation. The base slips readily into place on jack mountings . . . simplifies mounting, assembly, and maintenance.

CLARE RELAYS

"Custom-Built" Multiple Contact Relays for Electrical and Industrial Use

-C POWER SYSTEM FOR LARGE AIRCRAFT

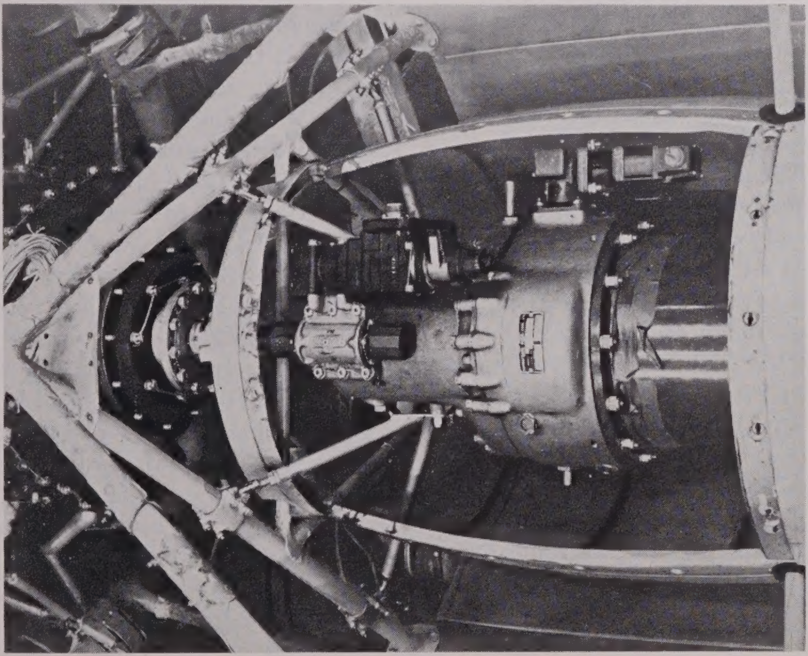
Developmental two-generator system holds promise of meeting new requirements imposed by increased power demands and by higher altitudes of flight



John G. Hutton

By Dr. J. G. HUTTON
General Engineering and Consulting Laboratory
General Electric Company

THE need of a new electrical system for aircraft, resulting chiefly from the growth in electric-power requirements for aircraft auxiliaries and increasing altitude at which projected aircraft are ected to fly, has led to an a-c system(1)(2)(3)(4)(5), v being developed. It is the purpose of this article to sent design and performance data of the various nponents mak- up the system, l to give some rational charac- stics of it on a)-generator de- opmental basis. No strict line of narkation could drawn on one e of which air- ft would have type of electric tem, and on the er have a dif- ent type. The e of airplane hether civil or itary) and the ticular duties to ch it is assigned typical points t had to be con- ered in making final selection power system. However, it was evident that airplanes ding more electric power than the approximate 50 kw he B-29 should be considered in the light of a new tric-power plant. Since voltage regulation, rather n current carrying capacity, determines the size cable on such large airplanes when a 30-volt d-c system is used, it was evident that any new electrical system would require a higher generated voltage. For this reason consideration was given to (1) a 120-volt d-c system and (2) a 208Y/120-volt a-c system.



Constant speed for driving aircraft generators. Part of the developmental two-generator system, this variable ratio transmission and alternator is now being installed on the B-35 and B-36

For reasons presented elsewhere(2), the a-c system selected was a 400-cycle three-phase 208Y/120-volt system, with the generators to operate in parallel and be driven from the main engines. Because of the speed range of the engines during a normal operational flight of the airplane, some form of automatically controlled variable-ratio transmission was necessary between each engine and generator. To successfully produce a parallel operated a-c system, each major piece of apparatus had to be first developed as a unit and then as part of an integrated whole. The components of the system will first be described separately and then in their relation to a two-generator developmental system; performance characteristics will be given where they serve to illustrate better the performance of the equipment to which they refer.

Variable-ratio Transmission

One form of variable-ratio transmission developed successfully is shown in **Fig. 1**. A cut-away view of this transmission, with the casing removed, is shown in **Fig. 2**; **Fig. 3** shows a schematic diagram of the transmission and its hydraulic system.

The transmission is a differential type of hydraulic drive using oil as a working medium. The cylinder

---

)"Why Tomorrow's Planes Will Have A-c Electrical Systems," by T. B. iday, *Electrical Manufacturing*, July 1943, p. 88.

)"Basic Considerations in Selection of Electric Systems for Large Air- ," by W. K. Boice and L. G. Levoy, Jr., GENERAL ELECTRIC REVIEW, ch 1944, p. 37.

)"Governor Requirements for Aircraft Alternator Drives," by W. K. e and L. G. Levoy, Jr., *AIEE Trans.*, July 1945, p. 534.

)"Constant-speed Drives for Aircraft Alternators," by C. J. Breitweiser, *E Trans.*, Nov., 1945, p. 763.

)"Governor for Variable-ratio Transmission Used in Developmental cycle Electric System for Large Aircraft," by P. F. Desch, D. E. Garr, and Hutton, *AIEE Trans.*, April, 1946, p. 194.

This article is so paged that, without mutilating other articles, it can be eniently removed for separate filing by tearing out pages 11 to 19.—ED.

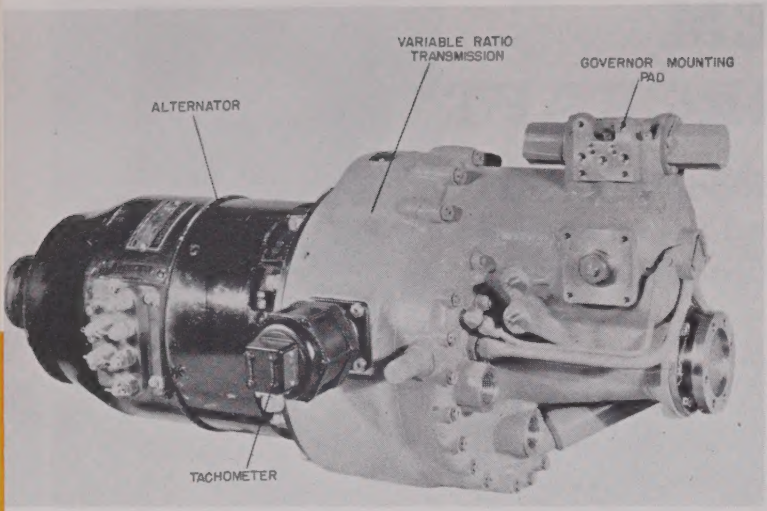
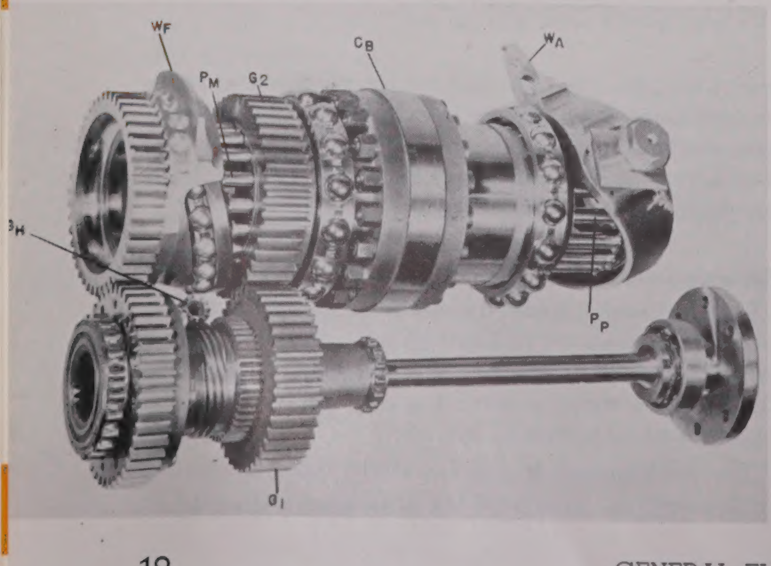


Fig. 1. Variable-ratio transmission and 400-cycle alternator

block C_B (**Fig. 2**) is driven from the input shaft through gears G_1 and G_2 at some speed proportional to the input speed to the drive. The righthand side of the block is essentially a variable-displacement hydraulic pump, the stroke of the barrel-shaped pistons and pushrods P_P being governed by the angular position of an adjustable swash plate W_A. The lefthand side of the block is essentially a fixed-displacement hydraulic motor, the swash plate W_F being fixed in angular position. A makeup gear pump, driven also through the input shaft, supplies oil, at an average pressure of approximately 250 lb per sq in. to flood continuously the cylindrical spaces behind the piston and the pushrods P_P and P_M.

With the adjustable swash plate in the position shown, the transmission operates at maximum overdrive; that is, the effective gear ratio is a maximum step-up. As the cylinder block rotates in the counterclockwise direction (**Fig. 2**) the near pushrods P_P in their upward movement are forced in by their bearing against the swash plate W_A and pump oil through the eccentric valve mechanism shown in **Fig. 4**. At the same time, the far pushrods P_P in their downward movement are retained in bearing contact with W_A by the makeup oil pressure.

Fig. 2. Variable-ratio transmission with case removed



Meanwhile, the hydraulic motor receives hi
pressure oil from the hydraulic pump through a seco
valving mechanism closely timed in its movement w
that of the first valve. The far pushrods P_M of
motor, in their downward movement, are in cont
with the fixed-angle swash plate W_F, and the rate
which they move out from the cylinders determines
rotational speed of W_F. This plate is geared throug
one-way clutch to the output spline of the transmissi

The angle of the adjustable swash plate W_A is var
automatically by governor action on a servomechani
from signals proportional to the output speed of
transmission. The quantity of oil pumped is prop
tional to the angle of the swash plate, and by corr
relationship between the speed of the cylinder bl
and this angle, a constant speed is obtained at
output shaft.

In the underdrive position—that is, with the tra
mission acting as a step-down gear—the valves all
the hydraulic motor to act as a pump, thus effectiv
making negative the relative speed of the fixed sw
plate to the cylinder block. The gear ratio of the tra
mission is thus less than one. When the movable sw
plate and the push rods are perpendicular, the in
and output sections of the transmission are lock
hydraulically and rotate as a unit. This is the straig
through drive ratio in which the input and out
speeds are the same.

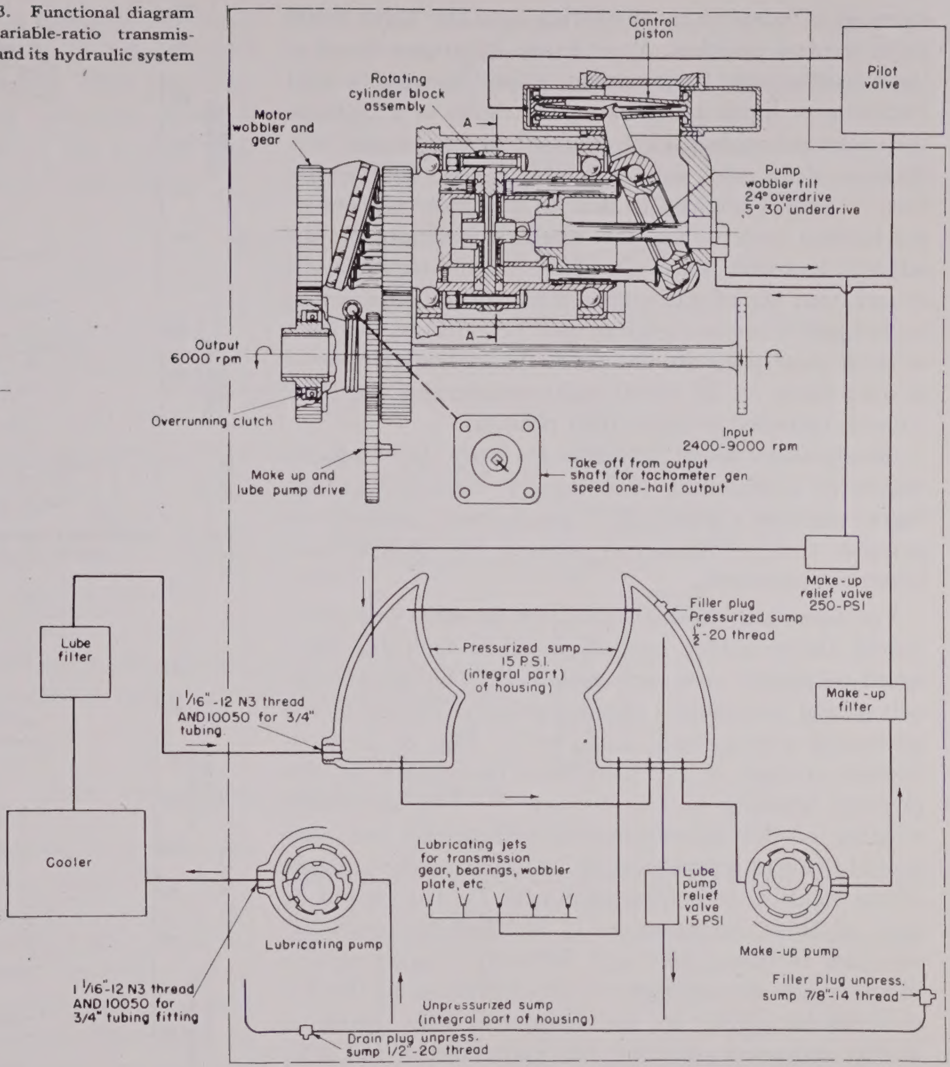
In accordance with aeronautical requirements, li
alloys are used in the variable-ratio transmiss
wherever possible. When dry, the unit weighs appro
mately 67 lb. The casing is of aluminum alloy throu
out. The cylinder block, swash plates, valves, gea
and shafting are of ball-bearing steel; the pistons, pu
rods, and parts of the adjustable swash plate assem
are of nitrided steel. Cylinder liners made of bro
provide bearing surfaces for the push rods. Bear
cages and the casing of both the make-up and lu
cating pumps are also bronze, and the gears of
pumps are of ball-bearing steel. Oil is used as the wo
ing medium, one suitable type being AN-03 light
Additional equipment necessary for the success
functioning of the variable-ratio transmission are
governor (described later), a rammed-air oil-coo
and a cartridge-type filter.

Representative performance characteristics of
model of the variable-ratio transmission are presen
in Table I and in **Figs. 5** and **6**. For an anticipa
cruising speed corresponding to an input speed to
transmission of 5400 rpm, the full-load over-all efficie
of the transmission is approximately 86 per cent.

Governor

The requirements for parallel operation of 400-cy
generators are such that automatic control of
angular position of the adjustable swash plate
necessary. This is achieved by means of an elect
hydraulic governor, shown in **Figs. 7(a)** and **7(b)**.
schematic diagram of the governor control circuit
shown in **Fig. 8**.

Fig. 3. Functional diagram of variable-ratio transmission and its hydraulic system


Control piston
Pilot valve
Rotating cylinder block assembly
Motor wobbler and gear
A
Pump wobbler tilt 24° overdrive 5° 30' underdrive
Output 6000 rpm
Overrunning clutch
Input 2400-9000 rpm
Take off from output shaft for tachometer gen speed one-half output
Make up and lube pump drive
Make-up relief valve 250-PSI
Filler plug Pressurized sump 1/2-20 thread
Pressurized sump 15 PSI (integral part of housing)
Lube filter
1 1/16"-12 N3 thread AND10050 for 3/4" tubing
Make-up filter
Cooler
Lubricating jets for transmission gear, bearings, wobbler plate, etc
Lube pump relief valve 15 PSI
Lubricating pump
Make-up pump
1 1/16"-12 N3 thread AND 10050 for 3/4" tubing fitting
Unpressurized sump (integral part of housing)
Filler plug unpress. sump 7/8"-14 thread
Drain plug unpress. sump 1/2"-20 thread

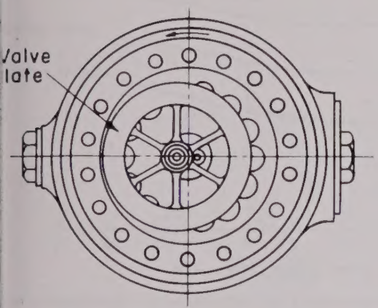


Fig. 4. Eccentric Valve mechanism (Section *A-A*, Fig. 3)

The signal for the governor is obtained from a small hree-phase a-c tachometer with a permanent-magnet eld. The three-phase tachometer generator *T* (**Fig. 8**) s driven through a helical gear (G_H in **Fig. 2**) at some peed proportional to the output speed of the trans-ission. The output voltage of the tachometer generator is rectified by means of the three-phase full-wave rectifier *SR3*, and fed through a variable resistance to the governor control coil *WC*. This control coil operates on a solenoid coupled mechanically to a three-land valve and biasing spring.

Under steady-state conditions, the force of the

TABLE I

PERFORMANCE OF VARIABLE RATIO TRANSMISSION WITH AEROVAC NO. 6 OIL—40-HP LOAD OUTPUT

Input Gear Ratio, 40-46; Output Speed, 6000 rpm;
Output Gear Ratio, 44-42; Make-up Pump Gear Ratio, 45-60

Trans-mission Input Rpm	Pump Rpm	Motor Rpm	Differ-ential Rpm	Differ-ential Hp	Hydraulic Unit Losses Hp	Hydraulic Unit Efficiency (Per cent)	Input Gear Losses Hp	Output Gear Losses Hp	Make-up Pump Hp	Pump Wobbler Angle	Input Hp	Trans-mission Eff. Minus Make-up Pump (Per cent)	Trans-mission Over-all Efficiency (Per cent)
2500	2174	5728	+3554	24.82	3.15	88.7	0.90	0.8	0.7	23.8	45.55	89.2	87.8
3500	3043	5728	+2685	18.75	1.99	90.2	0.88	0.8	1.03	13.15	44.70	91.5	89.5
4000	3478	5728	+2250	15.72	1.14	93.2	0.86	0.8	1.30	9.8	44.10	93.5	90.7
5500	4783	5728	+ 945	6.59	1.34	83.1	0.88	0.8	2.38	3.25	45.40	93.0	88.1
6500	5652	5728	+ 76	0.54	1.71	31.5	0.89	0.8	3.10	0.53	46.50	92.2	86.0
8000	6958	5728	−1230	8.59	2.30	78.9	0.90	0.8	4.6	1.36	48.60	90.9	82.3

solenoid is balanced by the spring, and the valve floats in its neutral position. Any change in output speed of the variable-ratio transmission, either because of load variation or input speed changes, results in a momentary increase or decrease in current to the control coil. Balance of the pilot valve assembly is thus temporarily lost, and oil is allowed to flow to and from the servomechanism controlling the angular position of the adjustable swash plate. The force on the servopistons is such that the effective gear ratio of the transmission is changed to restore original speed conditions. As soon as these conditions are obtained, the tachometer signal is once more at its steady-state value, and the pilot valve is returned to its neutral position.

Steady-state speed adjustments may be made by means of a trimming rheostat *R5*, mounted on the flight engineer's panel. For generators operating in parallel, this is also an adjustment for load division between generators.

For successful parallel operation of 400-cycle alternators, the machines' control should be such that their speed decreases with increasing load. The control circuit giving this desired speed regulation is part of the governing system and is shown in **Fig. 8**. Line-to-neutral voltage of the alternator is supplied to the primary winding of transformer T_1. The secondary winding of this transformer is mid-tapped and connected through a resistance R_1 to the primary windings of the identical transformers T_2 and T_3. The output of each of these transformers is rectified by means of selenium rectifiers *SR1* and *SR2*. By connecting the rectifier outputs subtractive, the difference in the d-c voltages is applied to the droop coil *WD*, which is wound concentrically with the main control coil *WC*. On no-load, the alternator line-to-neutral voltage produces equal signals in the rectifiers. Since the signals are subtractive, there is no current flow through the droop coil.

The secondary winding of the current transformer *CT*, whose primary is in the generator load circuit, is connected across the resistance *R1*. On load, a signal proportional to the alternator output current is therefore vectorially added to and subtracted from the voltage signal, thus producing unbalance in the outputs of rectifiers *SR1* and *SR2*. The unbalance results in current flow, smoothed out by means of the condenser-resistance network, *C1*, *C2*, and *R2*, through the droop coil. This coil is so connected that, on load, the flux produced is in the same direction as that of the control coil. This has the same effect as an increase in output speed of the variable-ratio transmission, and the governor acts accordingly. An approximate speed regulation of five per cent was found to be quite effective. By means of vector relations, it can be shown that the droop-coil is sensitive only to real power.(5)

Should an open circuit develop in the main control circuit, the governor would force the variable-ratio transmission into full overdrive, creating danger to both transmission and alternator from overspeed. To avoid this, a third coil *OS*, acting on its own magnet,

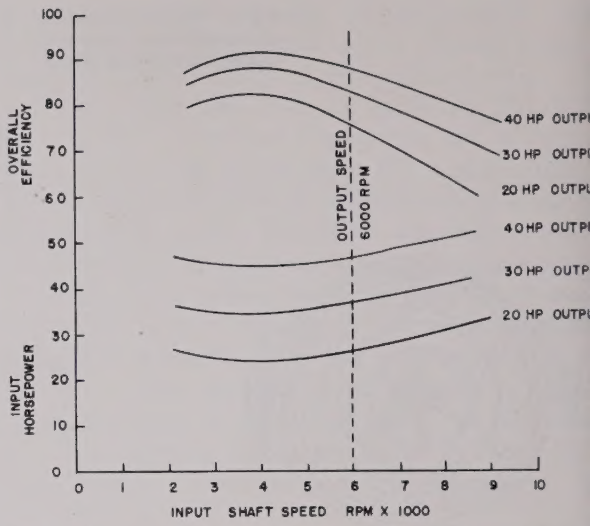


Fig. 5. Performance characteristics of variable-ratio transmission w
AN-03 oil at an inlet temperature of 130 F

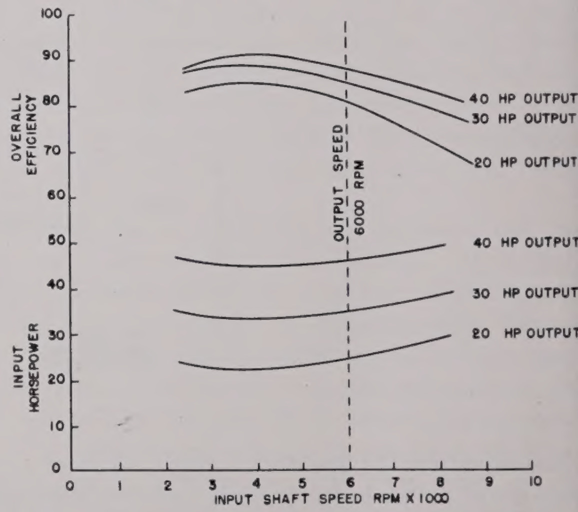


Fig. 6. Performance characteristics with AN-06 oil at 130 F

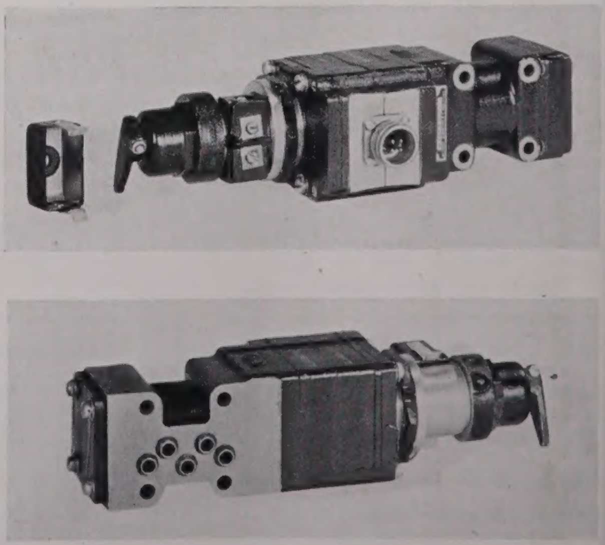


Fig. 7. Governor for control of variable-ratio transmission: (a)
ceptacle—side view; (b) oil-port side view

xial with the control magnet, is connected through entrifugal switch to the d-c bus. In the event of the tput speed of the drive exceeding 7000 rpm, the itch closes; and the resulting magnetic force is ficient to overcome the action of the control coil, s forcing the transmission into full underdrive.

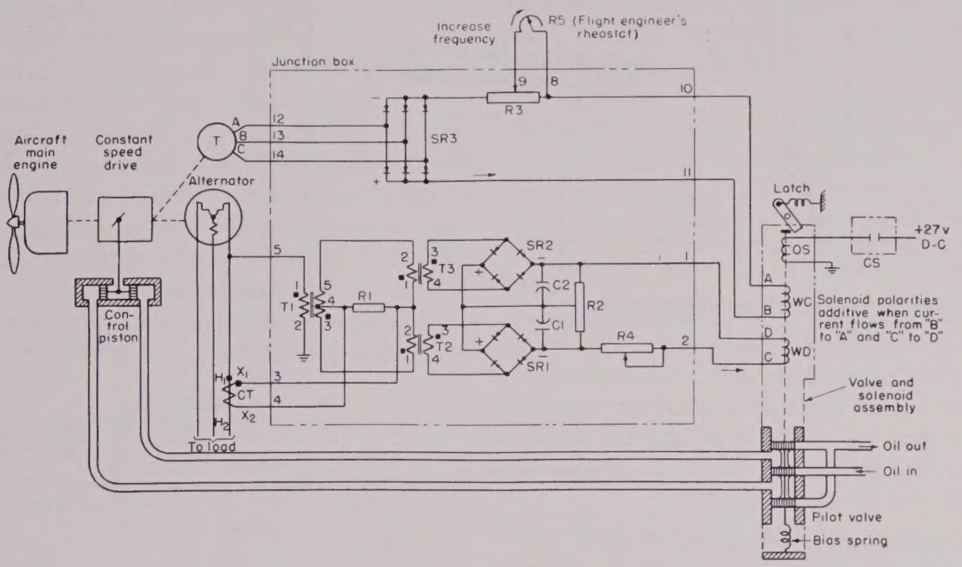


Fig. 8. Schematic diagram of governor control circuit

Performance data of the governors on a develop-ntal two-generator system have been very satis-tory. During tests in which one prime mover of the stem was accelerated at its maximum rate, while the ner remained at substantially constant speed, chronism was maintained without loss of system bility and constancy of voltage(5). The speed of sponse of the governor was such that the electrical gle between the generators reached its maximum and gan diminishing again before the end of the accelera-n period.

Table II

RATINGS OF 400-CYCLE THREE-PHASE 208Y/120-VOLT ALTERNATOR

Kva	Kw	PF	Volts	Current	Time
40	30	0.75	208	111	Continuous
60	45	0.75	208	167	5 minutes
80	60	0.75	208*	222	5 seconds

*At 60 kw, allowable voltage, 187 volts.

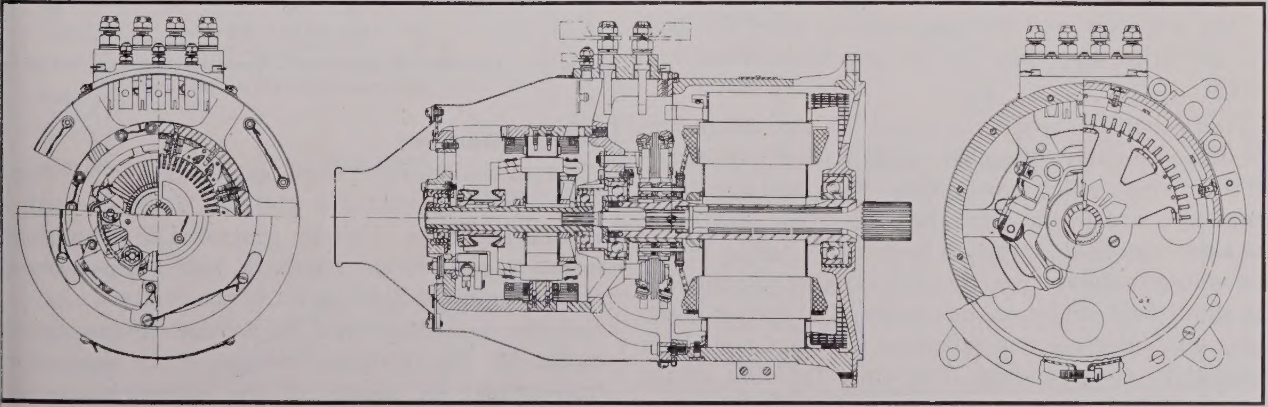


Fig. 9. Cross-sectional view of alternator and exciter

ternator

The power for the three-phase 400-cycle 208Y/120-lt a-c system is applied by means of an alternator with ectly connected exciter. The alternator is designed a main-engine drive through the variable-ratio nsmission described in the foregoing. Ratings of the ernator are shown in Table II, all values being at 400 cycles, three-phase, 6000 rpm, with cooling air equivalent to a pressure differential of six inches of water between air inlet and air exhaust through 3-in.-diam tubing.

A cross-sectional view of the alternator is shown in **Fig. 9**. The alternator is built with a directly connected exciter mounted on the end shield of the alternator. The alternator and exciter are directly coupled by means of a splined tooth connection. With this, and the four-bearing arrangement shown in **Fig. 9**, it is possible to dismount the exciter without disturbing the alternator.

To avoid transmitting engine pulsations to the rotating parts, a quill shaft is used, consisting of a

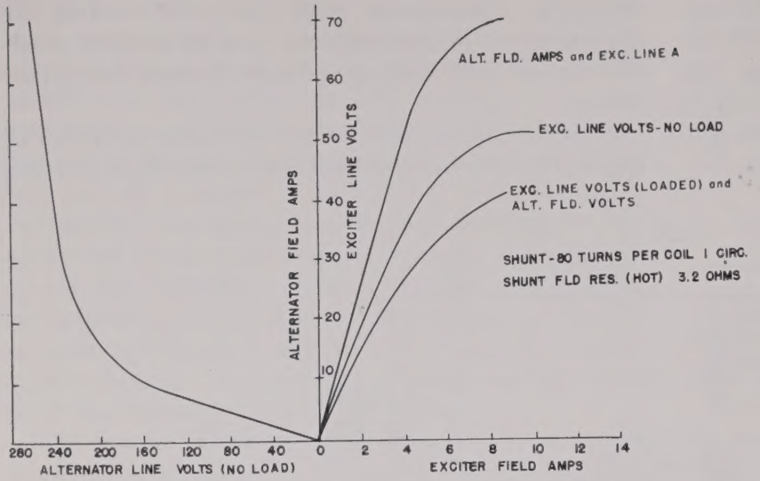


Fig. 10. Saturation curves for alternator and exciter

slender and flexible inner shaft and an outer shaft on which are assembled the rotating parts. The inner shaft drives the outer shaft by means of an internal spline at a point some three-quarters of the shaft length from the driving end.

Excessive vibration in the armature assembly is prevented by wrapping asbestos cloth on the inner shaft which in turn is press-fitted into the outer shaft. The success of this type of mounting was well illustrated in test. With two consecutively firing cylinders of the engine not functioning, torque pulsations were heavy, but no excessive vibration was transmitted to the alternator.

In general, the electrical features of the alternator are conventional. However, in accordance with aircraft requirements of compactness and lightness, some special characteristics are necessary. Cooling is provided by air-blast ventilation, and the windings are worked at high current densities. Glass insulation is used wherever feasible. Special silicon steels are used for the armature and field magnets to allow the high flux densities necessary for the machine rating and weight.

The exciter is directly coupled to the alternator. Excitation for the alternator rotating field is furnished by the exciter, which is connected through the machine terminal board to the alternator slip rings. Control of the alternator field excitation is accomplished by means of a voltage regulator activating a variable resistance in the shunt field circuit of the exciter. The exciter is six-pole, with interpole and pole-face windings and slight cumulative compounding. The chief function of the latter in this instance is to prevent too heavy depression of the exciter voltage if generators were synchronized in phase opposition.

Brushes were treated for high-altitude operation. On the exciter, adjustment of the brush position was permitted by means of slots in the end shield.

Performance characteristics of the combination exciter and alternator are presented in **Figs. 10, 11,** and **12.**

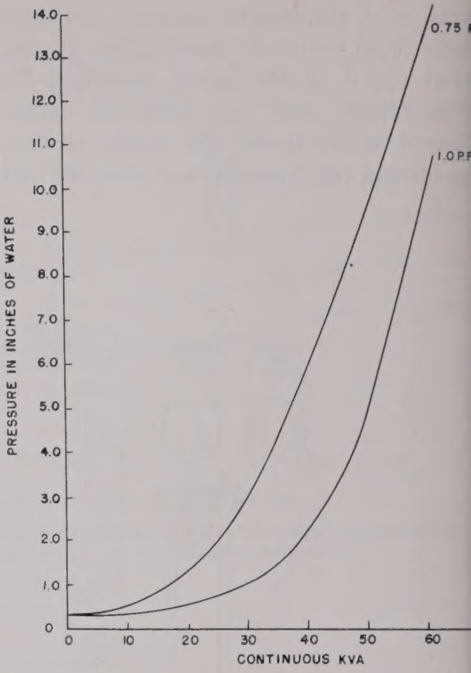


Fig. 11. Output of alternator vs. cooling air pressur
sea level

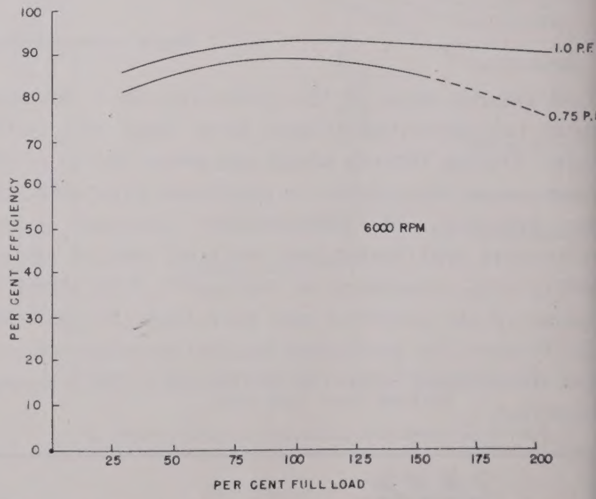


Fig. 12. Alternator efficiency curves. Maximum efficiency is 92.5 per ce
at approximately 110 per cent load

Voltage Regulator

As previously mentioned, excitation for the rotat field of the alternator is obtained from a small, s excited generator. Voltage control is accomplished means of a voltage regulator activating a varia resistance in the field circuit of the exciter.

A schematic diagram of the voltage regulator is sho in **Fig. 13**. The three line voltages of the alternator transformed by means of the open-delta-connec potential transformer. The secondary windings connected through resistors and compensating react to a selenium rectifier. The electromagnetic coil of voltage regulator is connected in series with a volta adjusting rheostat to the output terminals of rectifier. Signals to the control coil are thus proportio to the average of the three line-to-line terminal volta of the alternator. The voltage-sensitive element i carbon pile connected in series with the exciter field a tivated through a spring-supported movable armare by the electromagnet of the control coil.

The voltage-adjusting rheostat is set to maintain a nstant current in the control coil. Variations from is current that are due to variations in the alternator rminal voltage resulting from loading conditions use the electromagnet to change the pressure on, and erefore the resistance of, the carbon pile. A change in e field current of the exciter results, restoring the ternator terminal voltage to the value for which the gulator is set. This value may be anywhere between 0 and 210 volts, as desired.

Stabilizing action is obtained by means of the pacitor connected in series with the auxiliary winding the electromagnet core and across the exciter terinals. A variation of this may be obtained by replacg the capacitor with a suitable transformer.

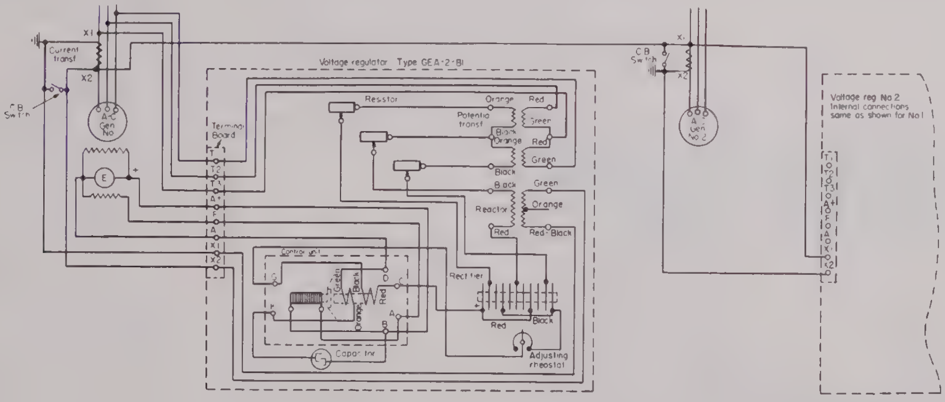
For parallel-operated generators, reactive-load divion may be obtained by the cross-current method of compensation as in industrial practice, the compensating reactor and current transformer X_1X_2 being connected as shown (**Fig. 13**). For nonparallel operation, the secondary winding of the current transformer is short circuited.

Motors

Materials used in the construction of motors for 400-cycle aircraft electrical systems follow the same specifications as those used in the generators. Prerequisites are low weight per unit volume and good electrical and magnetic characteristics. Performance characteristics of two developmental induction motors, one continuously rated and the other intermittently rated, are presented in **Figs. 14** and **15**.

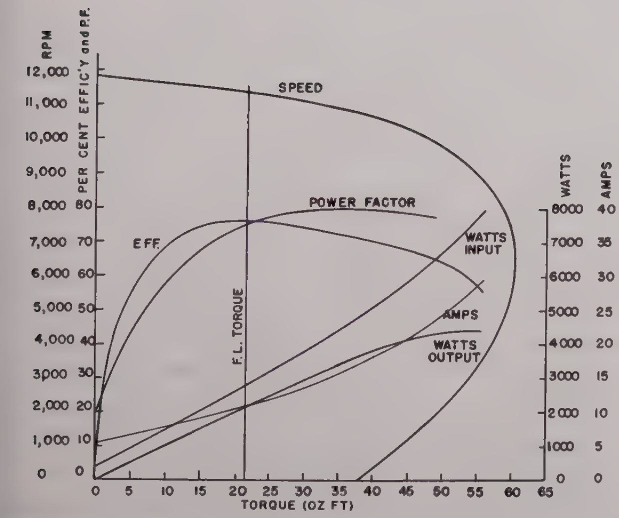
Fuses

With the growth in available electric power on aircraft, the need for fast and sure protection has become



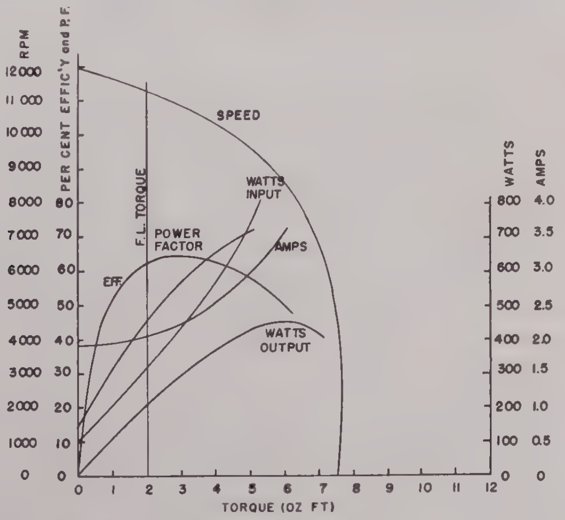
Note Only paralleling connections are shown for unit No 2. Other connections same as shown for unit No

Fig. 13. Schematic diagram of voltage regulator



NTINUOUS DUTY RATING
PEN DESIGN
EMP. RISE OF WINDING AT RATED LOAD TORQUE
GROUND LEVEL - 40.5°C
OCKED ROTOR AMPS - 51.2
OCKED ROTOR P.F. - 61.3 %

ig. 14. Induction-motor-performance characteristics for continuous duty for motor rated 3 hp at 10,800 rpm



INTERMITTENT DUTY RATING -
DUTY CYCLE, ONE MINUTE ON,
TWENTY MINUTES OFF
OPEN DESIGN
TEMP. RISE OF WINDING AT RATED LOAD TORQUE
GROUND LEVEL - 40.5°C
LOCKED ROTOR AMPS - 6.5
LOCKED ROTOR P.F. - 73%

Fig. 15. Motor-performance characteristics for intermittent duty (one minute on, twenty minutes off) for a two-ounce-foot motor with speed rating of 10,200 rpm

increasingly important. While electrically operated circuit breakers would provide good protection, the number needed on the exposed circuits of a military aircraft would become prohibitive from the viewpoint of weight. In combat, it is also necessary to continue operation of essential apparatus as long as possible, even at the expense of the generating plant. A light-weight fast-clearing fuse and light multichanneled circuits in vulnerable areas offered one solution to this problem.

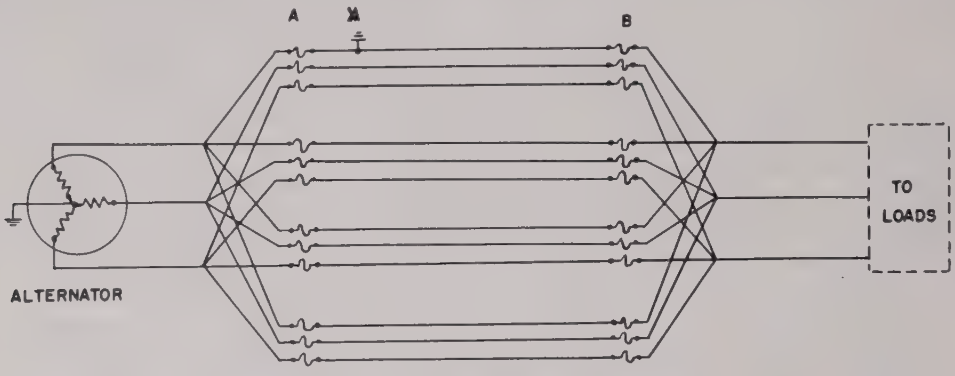


Fig. 16. Schematic diagram of fused mesh network

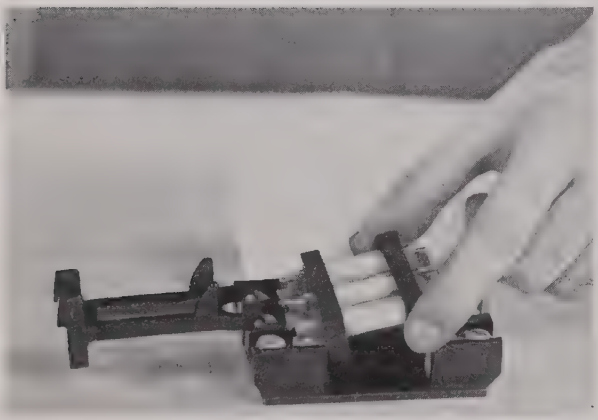


Fig. 17. Three-phase fuse and holder, with fuse in unlatched position

A schematic diagram of a proposed "fused mesh network" is shown in **Fig. 16**. Should a fault occur at point *X*, fuse *A* would blow first, followed by fuse *B*. Three channels would remain to carry the load until the fault could be repaired and the fuses replaced. A three-phase fuse and holder is shown in **Fig. 17**, with its time-current characteristics presented in **Fig. 18**. Similar characteristics for a single-phase fuse are shown in **Fig. 19**.

In laboratory tests, a model fused-mesh network was set up to transmit power from a two-generator 400-cycle a-c system to a group of motors. With the motors running, one branch of the network was grounded; there was no perceptible pause in the operation of the motors.

Instruments

In accordance with aircraft practice, instruments for use on the 400-cycle a-c system were made small and light, without sacrificing necessary accuracy in reading.

The ammeter has a current range of 0–2 amp a
when connected in the secondary circuit of a 12
current transformer, has a measuring range of 0–
amp. The instrument is of the moving-iron-attract
type and is equipped with a flux distribution for s
adjustment. Designed to withstand shock tests,
instrument is back-of-panel mounted. The panel m
be either of magnetic or nonmagnetic material with
appreciably changing the instrument calibration.

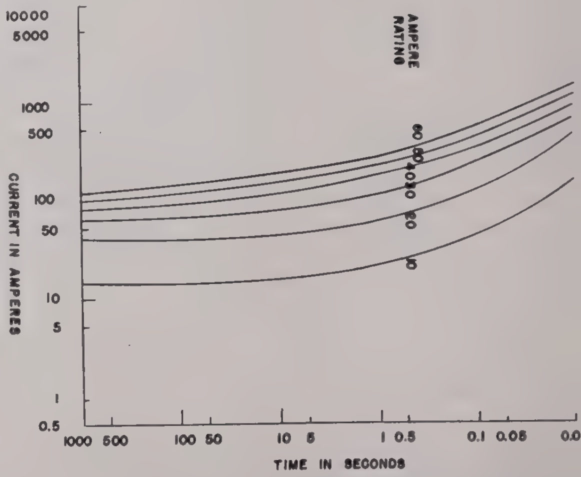


Fig. 18. Fuse characteristics of three-phase 208Y/120-v 400-cycle circ

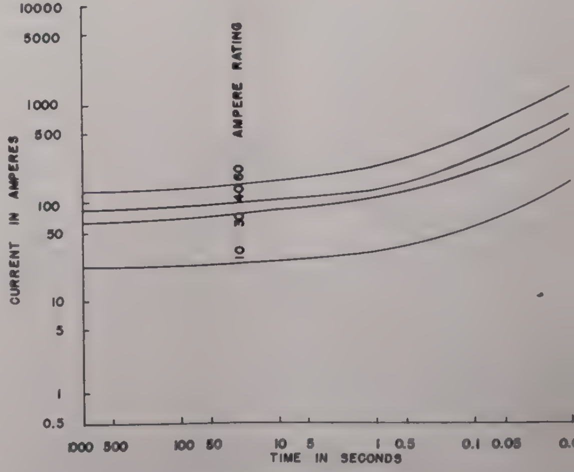


Fig. 19. Fuse characteristics of single-phase 400-cycle circuit

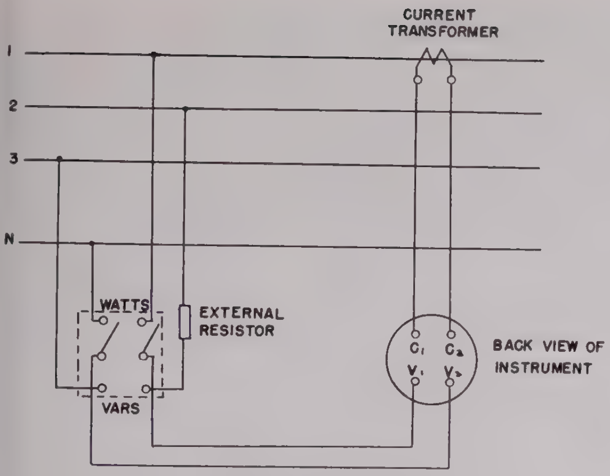


Fig. 20. Connections for Kw-kvar meter

ammeter is equipped with a zero adjustor for screwdriver operation.

The voltmeter is structurally similar to the ammeter and has a 0–250-volt range for line-to-line connection in the 208Y/120-volt a-c system.

On the three-phase 208Y/120-volt system, power is measured by means of a single-phase wattmeter, assuming balanced three-phase power. The instrument has its voltage coil connected line-to-neutral; the current coil is connected in series with the ammeter in the secondary circuit of a 125:1 current transformer. Thus, for 133.3 calibrating watts, the scale capacity of the instrument is 0–50 kw. Reactive power is measured by means of a changeover switch and external resistor, connected as shown in **Fig. 20**. Mounting is similar to that of the voltmeter and ammeter. Scale adjustments are made by means of small rheostats connected in series with the potential element of the wattmeter.

The frequency meter is an electrodynamic-type instrument, the moving-coil element being connected in series with the impedance elements. The impedance elements consist of a capacitance, inductance, and resistance adjusted for broad series resonance at a frequency of approximately 400 cps. Scale adjustments are made as in the wattmeter, and mounting is as in the foregoing. The instrument is magnetically shielded.

System Performance

Extensive preliminary tests were carried out on a developmental two-generator system set up without any attempt to simulate circuit resistances and reactances of an airplane network. The first tests were made in the laboratory using two 9-cylinder 450-hp air-cooled radial-type aircraft engines, each driving, through a step-up gear and the variable-ratio drive, a 30-kw 40-kva 400-cycle alternator. These engines were so selected that acceleration rates and torque-pulsation effects expected in actual installations could be simulated.

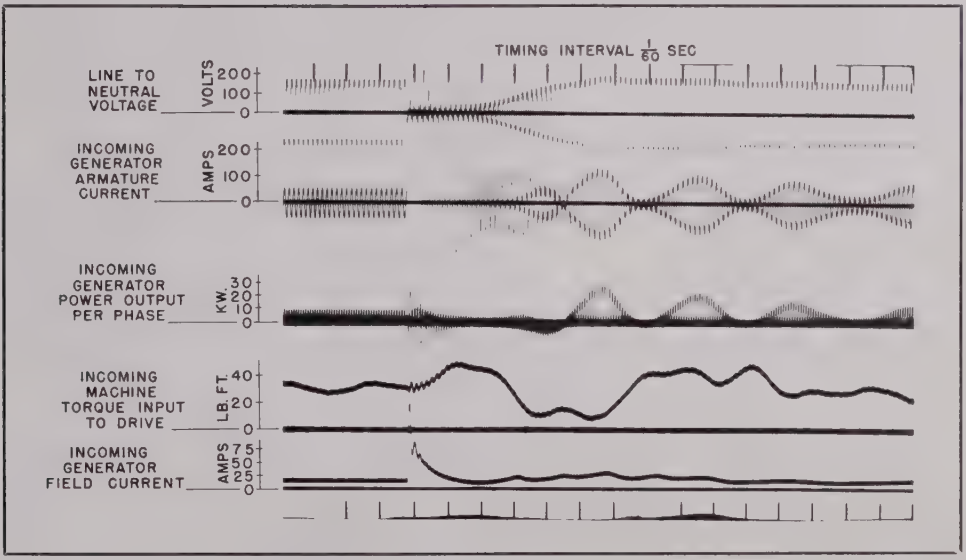


Fig. 21. Oscillogram of synchronizing disturbance

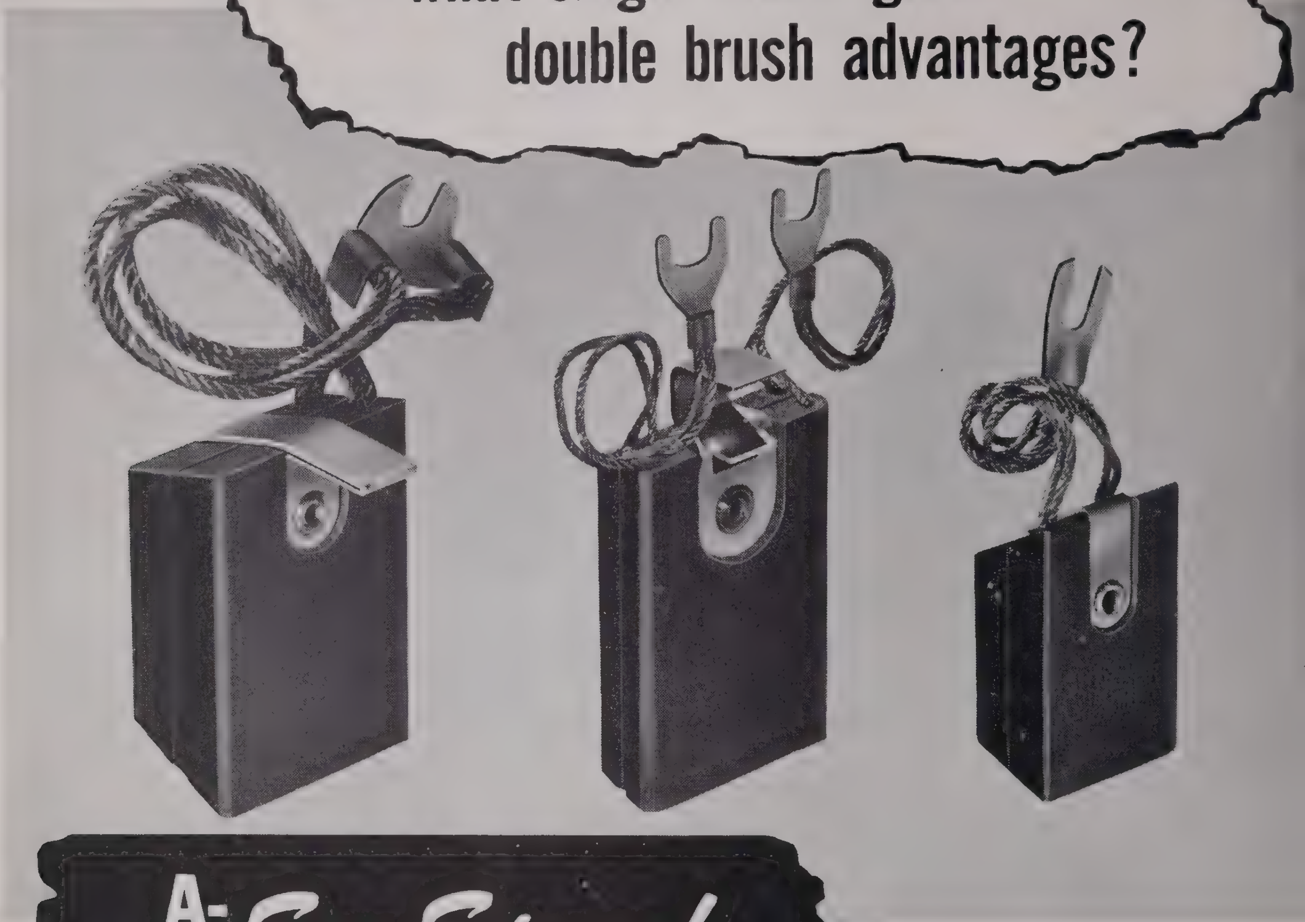
Various methods of synchronization were tried, the most severe disturbances resulting from synchronization with the alternator voltages in phase opposition. At the instant of closure of the synchronizing switch, the effect is the same as a three-phase short circuit on the generator. In spite of this, synchronization was readily accomplished, as indicated in **Fig. 21** which is part of an oscillogram taken with the generator voltages initially in phase opposition. Several hundred hours of operation were gained on the developmental two-generator system and numerous oscillograph records obtained of various aspects of the system performance.

Meanwhile, a B-29 airplane was modified for the installation of a similar system. Successful flight operation was accomplished in September 1946 and has continued since. The success of these initial flight tests was sufficient to warrant the installation of the 400-cycle a-c system on the B-35 and B-36 airplanes.

Acknowledgment

The author wishes to express appreciation to the Sundstrand Machine Tool Company, Rockford (Ill.), for the use of photographs of the variable-ratio transmission.

Q-what single brush gives double brush advantages?



A-*See Speer!*

Speer Multiflex Brushes materially improve contact, reduce vibration, give more uniform wear and longer brush life—all the advantages of double brushes. Yet no special adapters or expensive changes are needed for their installation. Multiflex Brushes slide right into conventional single-brush holders!

These, plus other operating and maintenance advantages, come with the use of Multiflex Brushes because of their inherent simplicity of design. A simple hammer plate attached to one section and overlapping the other, assures equalized spring pressure.

Simplicity of design for attaining increased efficiency in AC and DC motors and generators is only one of the many characteristics of all Speer brushes. Let Speer match brushes—mechanically and electrically to your machine and provide the right solution.

Speer
CARBON COMPANY
ST. MARYS, PENNA.

brushes · contacts · welding electrodes · graphite anodes · rheostat discs · packing rings · carbon part

CHICAGO · CLEVELAND · DETROIT · MILWAUKEE · NEW YORK · PITTSBURG

A WEDDING DRESS WENT INTO HIS ELECTRIC MOTOR

In 1833 Thomas Davenport, a poor Vermont blacksmith, saw an electric magnet drawing out bits of iron from a heap of rubble. Believing that he could apply magnetism to the propulsion of machinery, he bought the device and took it apart to see how it was made. Later when he set about constructing a larger magnet, he was unable to complete it for lack of silk to wind the wire—until his wife gave him her wedding dress!

The following year, still working entirely with electro-magnets, he achieved his great success. Though few people realize it, all electric motors in the world today derive from Davenport's invention. Today's motors are equipped with antifriction bearings—many of them made by SKF. For SKF units always insure that shafts are properly centered, uniform air gaps maintained—the rotors staying in the center of the magnetic field—and only infrequent lubrication needed.

SKF makes so many types of bearings that SKF engineers are expert in prescribing . . . .

THE RIGHT BEARING FOR THE RIGHT PLACE

SKF
BALL AND ROLLER BEARINGS

SKF Puts the RIGHT BEARING in the RIGHT PLACE

SKF INDUSTRIES, INC., PHILA. 32, PA.

HIGH-VOLTAGE RECTIFIER CIRCUITS . . . Part I

Circuit, transformer, and tube characteristics that determine the type of circuit preferred. Filament-transformer economy. Filter-circuit requirements

E V DeBlieux

By E. V. DeBLIEUX
Power Transformer Engineering Division
Pittsfield Works, General Electric Company

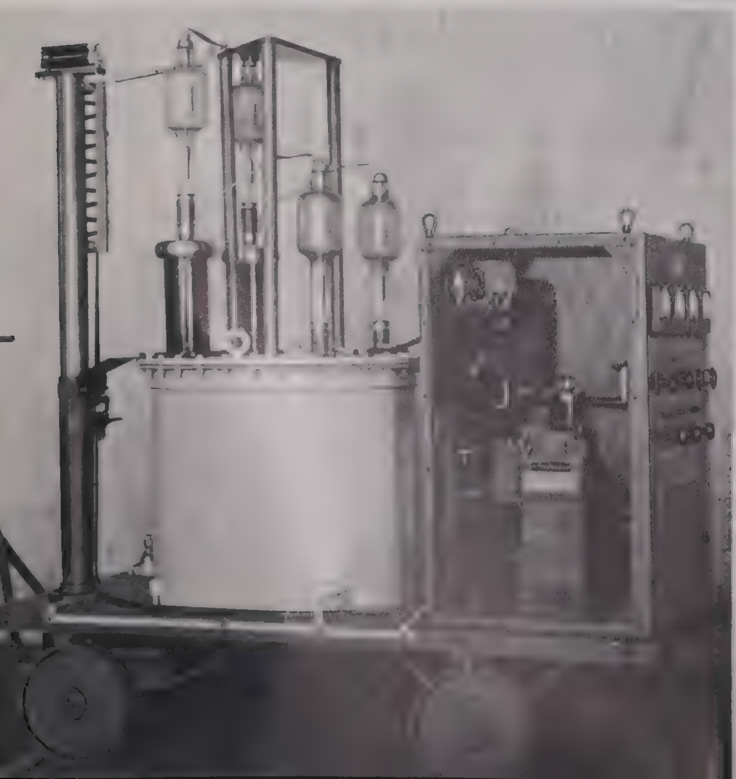
RECTIFIERS having ratings from tens of thousands to millions of volts and from milliamperes to a few amperes are generally considered as high-voltage rectifiers (**Figs. 1** and **2**) and are used in such applications as: direct-current testing; communication systems; cathode-ray oscillographs; x-ray apparatus; electron microscopes; electron accelerators; and industrial precipitation processes.

For a more comprehensive picture of high-voltage rectifier-circuit design, a brief description of power rectifiers will be given to illustrate some of the important differences between high-voltage and power rectifier circuits. Power rectifiers, having ratings ranging up to a few thousand volts but with currents from hundreds to thousands of amperes, are used in such applications as: industrial processes requiring large currents; power transmission systems; and electric railways.

Factors That Determine Preferred Circuits

The two general types of circuit used in rectifier operation are single-way and double-way circuits. The single-way rectifier is a rectifier in which the current between each terminal of the a-c voltage circuit and the rectifying element (or elements) conductively connecte to it flows in only one direction.

Fig. 1. This portable rectifier is capable of producing 100,000 volts, 100 ma. It is used to apply high-voltage d-c tests to cable



The double-way rectifier is one in which the curren between each terminal of the a-c voltage circuit an the rectifying element conductively connected to i flows in both directions.

In power rectifier circuits, efficient utilization c copper, smooth direct voltage, and the practical prob lems of transformer design and construction favor th use of single-way circuits.

In an earlier article(1), it was stated that double-wa circuits are preferable for high-voltage rectifiers for th following reasons:

(1). The necessity of interlocking pairs of trans formers to prevent core saturation is removed.
(2). Danger of overvoltage from transients i limited.
(3). Better regulation is provided.
(4). Loss of efficiency is negligible.
(5). Inverse voltage per tube is reduced.

Core Saturation

In a single-way rectifier circuit, each anode an associated transformer winding normally carries cu rent once per cycle. There is, therefore, a d-c componen in each winding current. To prevent saturation of th transformer core caused by this component, an eve number of d-c windings is provided with each primar winding, so connected in pairs that the windings c each pair carry current at 180-deg intervals. When on d-c winding is active, the other is inactive; thus eac winding of the pair is active only half of the time.

Consequently, it is necessary for each d-c winding t occupy the position of a full normal secondary trans former winding to avoid high reactance, high regula tion, and excessive leakage fluxes with their attendan losses.

Also, the reactance of all d-c winding line-to-neutra sections should be equal and a symmetrical phase dis placement maintained for the output voltage to b free of spurious harmonics.

These requirements are easily met in low-voltag rectifiers by interleaving or interlacing the d-c winding

---

(1)"Characteristics, Design, and Applications of Rectifier Transformers. by E. V. De Blieux, GENERAL ELECTRIC REVIEW, Parts I, II, and III, Sept Oct., and Nov., 1937, pp. 412, 481, and 539.

This article is so paged that, without mutilating other articles, it can b conveniently removed for separate filing by tearing out pages 22 to 25.—E accordance with conventional transformer prolures. In high-voltage circuits, this procedure is made practical by the high voltage existing between the irs of windings. The higher the direct voltage, the ore difficult and costly it becomes to properly intere the pairs of transformer windings.

ervoltage from Transients

Many of the single-way circuits have floating points interconnection. Transient conditions may cause ese points to shift from their steady-state potential, ich might result in serious overvoltage(2) to ground d to other points in the circuit.

In double-way circuits, two tubes are oppositely nnected to each d-c winding terminal. Should trannt voltages of either polarity occur at any terminal, e or the other of the tubes will start conducting and nit the transient voltage.

gulation

When low voltage regulation is required, circuit eference may be different from that when higher gulation is permissible. In these instances, polyphase rcuits such as six-phase double-way circuits, because their inherently lower regulation, may be preferable the higher-regulation single-way circuits.

ficiency

Although the load current passes through two rectir tubes in series in double-way circuits, the loss of iciency from the series arc drops is negligible because the high d-c voltage.

In a single-way circuit the loss in d-c voltage due to gulation includes the arc drop of only one tube beuse the load current, in flowing through the rectifier rcuit, passes through the arc of only one rectifier tube. some circuits, the load current is subdivided and ws through two or more rectifier tubes in parallel; is, however, is equivalent to one rectifier tube.

In power rectifiers with output voltages in the range 300 to 600 volts the arc drop of the mercury-arc ctifier, which is in the order of 15 volts, represents a ss of several per cent in efficiency.

In high-voltage rectifiers with output of 30,000 volts higher, the arc drop of two high-vacuum tubes in ries, which may be several thousand volts, represents loss of approximately one per cent in efficiency.

verse-voltage Limit

In high-voltage rectifiers, the output voltage is ually considerably more than the inverse voltage nit of the rectifier tube. This condition requires the e of two or more rectifier tubes in series to reduce the verse voltage per tube to a permissible value. This ctates the use of a double-way voltage-multiplier or scade rectifier circuit.

The use of the cascade rectifier circuit with the steps the cascade phase-displaced has another beneficial sult in that it produces a smoother output voltage than would otherwise be obtained. This is important in connection with filter circuits, to be considered later.

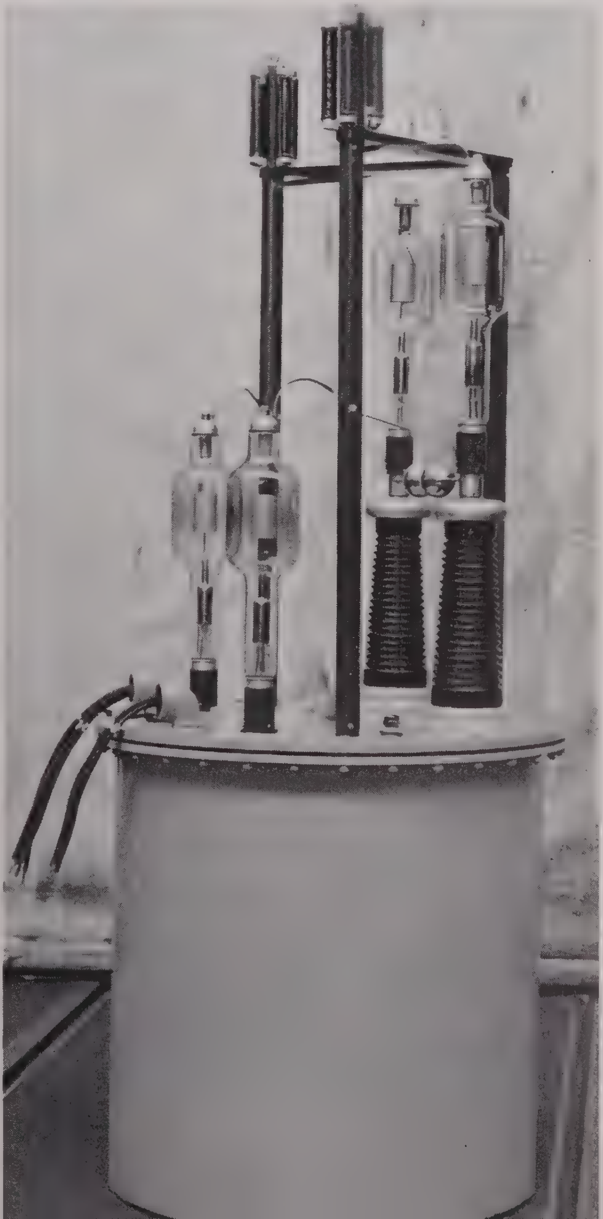
In high-voltage rectifiers the characteristics of the available tubes are major factors in the choice of circuit.

Tube Characteristics

Pool-type rectifier tubes are usually not satisfactory for high-voltage applications because this type of tube does not present a high impedance to the flow of current when the anode is negative. Also because of the relatively long time required to ionize and deionize, this type is not satisfactory at frequencies above a few hundred cycles per second. Furthermore, pool-type rectifier tubes are nonconducting until a critical voltage is reached, at which time the tubes suddenly start conducting.

Contrasting with a gas-filled rectifier tube, high-vacuum tubes exhibit a smoothly varying arc-drop characteristic up to the emission limit of the cathode, the arc drop being determined by the three variables, cathode temperature, plate voltage, and plate current. The arc drop of high-vacuum tubes is very high in comparison with that of gas-filled tubes.

Fig. 2. Kenotron rectifier, producing 300 ma at 75,000 volts. Note the spark gap at the base of the two tubes on the right



---

(2)"High-voltage, Steel-tank Mercury-arc Rectifier Equipments for dio Transmitters," by J. C. Reed, Part II, *Jour. of IEE*, Oct., 1945, p. 453.

High-vacuum Tube Limitations

Hot-cathode and pool-type tubes both have a steady-state and a transient overload current limit that is determined by their heat-dissipating capacity. The transient overload limit for pool-type tubes is considerably higher than for hot-cathode tubes.

Hot-cathode tubes also have an electron-emission limit that is determined by the cathode characteristics. The circuit must be so designed that the peak current required does not exceed the emission limit of the cathode.

Both hot-cathode and pool-type tubes have an inverse voltage rating which, if exceeded, might cause arcbacks. Arcbacks are more serious in hot-cathode tubes because this type of tube may be seriously damaged by a single arcback, whereas pool-type tubes may withstand a number of arcbacks without serious damage.

Although the practical problems of rectifier-transformer design and manufacture largely determine the choice of rectifier circuit for power rectifiers, the limitations of the available rectifier tubes determine the choice of rectifier circuit for high-voltage rectifiers.

Efficient Utilization of Transformer Copper

In a preceding section it was explained that each winding of the pairs of d-c windings is active only during a portion of one half-cycle when used in a single-way circuit. In a double-way circuit, each pair of windings is replaced by a single winding which is active during both halves of the cycle and so approaches a conventional power transformer in efficiency of utilization of the transformer.

Short-circuit Forces

Because of the low value of load current in high-voltage rectifiers, conductors of small cross-section are used in the d-c winding. Unless coils and turns are properly supported, the short-circuit strength will tend to be less than that of the windings of power rectifier transformers, which are of larger copper cross-section. In many cases, the current-limiting characteristics of certain types of tubes used in high-voltage rectifiers and/or the small capacity of the power supply limit the short-circuit currents to a value that the rectifier winding can withstand. However, these favorable conditions may not exist, and other precautions may be necessary when pool-type tubes are used (because they do not have current-limiting characteristics) and in industrial applications where the power supply may be of large capacity.

Rectifier tubes can function as current limiters for only a brief time because of the severe electron bombardment and heating of the anode under these conditions. If the filament is of the coated type, damage to the coating may occur.

Economy in Filament Transformers and Tubes

In the use of filament transformers and tubes, the economy of a circuit is important in evaluating the relative merits of different circuits.

Circuits so arranged that one filament transforn supplies two tubes or that have some of the filamer at or near ground potential are most economical w respect to filament transformers.

However, a circuit which results in a saving insulation of filament transformers may make ex insulation necessary in the plate transformer, resulti in extra cost of that component. The net change in c must be evaluated.

Furthermore, circuits which work tubes at th current and voltage ratings and require the le number of tubes make economical use of tubes. other words, circuits in which average current, pe current, and inverse voltage match the correspondi characteristics of the tubes are preferred.

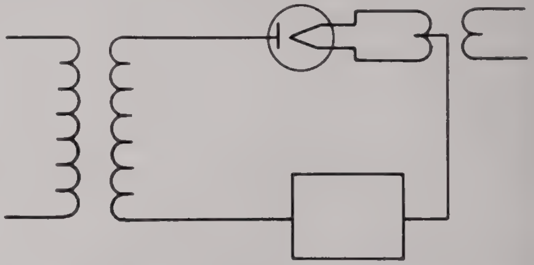


Fig. 3. Half-wave single-way circuit with centertap filament transform

Filament Transformers

Two types of filament transformers are used in hi voltage rectifier circuits. In one type (**Fig. 3**), the winding is connected to the midpoint of the filame winding. With this arrangement, one half of the lo current flows in each half of the filament winding.

Another type of filament transformer omits the m tap and connects the d-c winding to one end of filament transformer winding. With this connecti the load current divides and flows to the rectif cathode through two paths, one through the dir connection to the cathode and the other through filament transformer winding. The resultant unequ division of current results in unequal currents being to the two ends of the cathode filament. The divisi of the load current between the two paths depends their relative impedance. With this arrangement, portion of the load current that flows through the fi ment transformer winding is an exciting current and p duces additional flux in the filament transformer co

Except in directly heated cathodes, the per cent the total current fed to each end of the cathode filame is of minor importance. Even for directly heat cathodes it is not a limitation unless the difference the two currents is very large or uniform distributi of electron emission is essential. Therefore, the m serious effect is the increase in core flux density. H serious this is depends on the ratio of the load curre to the normal exciting current and the normal core f density.

The distribution of emission from directly heat filaments of gas-filled tubes is affected by the phase the filament current with respect to the load curre When the filament voltage is of the same order nitude as the tube arc drop, and the load current oaches tube rating, it is important to have a quadra- phase relation of filament current and load current. ith in-phase excitation of the filament transformer with the load-current connection brought to one of the filament winding (rather than to the midtap) concentration of the load current towards the end hich the connection is made may be appreciable. er these conditions center tapping of the filament ling may be preferable.

the peak value of the load current is equal to the value of the exciting current, the effect will be to ble the exciting current and increase the maximum density every other half-cycle.

he normal exciting current of filament transformers sually of the order of 30 per cent of the rated nent current. For such a design, when part of the current flows through the filament winding, and peak of this load current is equal to 20 per cent of peak filament current, the peak flux in the filament sformer core will be increased approximately 25 cent. In general, it can be assumed that a con- atively designed filament transformer without mid- will operate satisfactorily provided the cathode current is not more than approximately 50 per cent he filament-winding peak-current rating.

the cathode-filament heating must be uniform, or e load current is relatively large, the quadrature nection must be used.

r Requirements

n the preceding sections it was shown that the pler circuits, because they require fewer tubes, sformer windings, etc., are preferable for economic sons. This may not be true if filtering is necessary. f a d-c voltage with a small ripple is essential, filter acitors are used to reduce the ripple in the d-c age. The size and cost of the filter capacitor in- se with the amplitude of the ripple that must be uced. Both filter and rectifier circuits should be igned to use standard capacitors because of the her cost of special capacitors. For high-voltage lications, filter capacitors are relatively less expen- than filter reactors. Therefore, when filters are essary, the increased cost of the filters required for simpler circuits must be balanced against the reduc- n in cost of transformers.

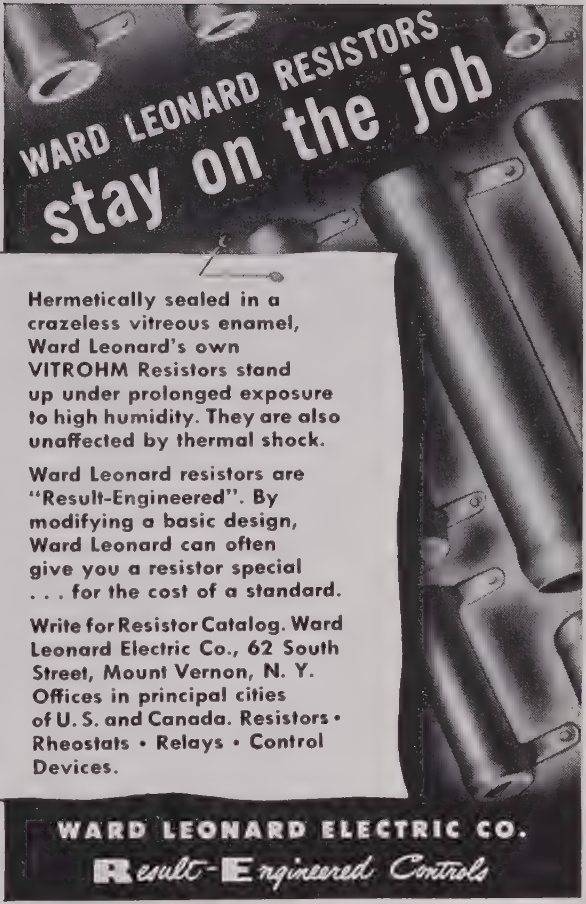
General rules for the choice of high-voltage rectifier uit may be stated as follows:

(1). If the load current is small, the number of recti- ier units to be kept to the minimum, or ripple voltage s unimportant, single-way circuits are preferable.

(2). For larger load currents, double-way and ridge circuits are preferable.

(3). For small-current very-high-voltage applica- ions, voltage-multiplying circuits are preferable. For higher-current very-high-voltage applications, ascade circuits are preferable.

(To be continued)



Hermetically sealed in a crazeless vitreous enamel, Ward Leonard's own VITROHM Resistors stand up under prolonged exposure to high humidity. They are also unaffected by thermal shock.

Ward Leonard resistors are "Result-Engineered". By modifying a basic design, Ward Leonard can often give you a resistor special . . . for the cost of a standard.

Write for Resistor Catalog. Ward Leonard Electric Co., 62 South Street, Mount Vernon, N. Y. Offices in principal cities of U. S. and Canada. Resistors • Rheostats • Relays • Control Devices.

WARD LEONARD ELECTRIC CO.
Result-Engineered Controls

MPB MAKES MORE THAN 40 different types & sizes of miniature ball bearings

Available? Yes! Small quantities on your desk within 48 hrs.

Close Tolerance? Yes! ABEC #5 or better, as required.

Special Bearings? Yes! Complete service within our size range — 1/8" to 5/16" O. D.

Prices? Much less than you would expect for these precision components.

Specifications? Complete in our NEW Bulletin GE-28. A copy will be mailed promptly on request

MINIATURE Precision BEARINGS
INCORPORATED
KEENE, NEW HAMPSHIRE, U. S. A.

Nothing Rolls Like a Ball . . .

NEW DEPARTURE
BALL BEARINGS

NEW DEPARTURE • Division of GENERAL MOTORS • BRISTOL, CONNECTICUT • Branches in all principal cities

A guy can dream can't he?
PRESIDENT

Daydreams of executive grandeur are as natural as their realization is commonplace . . . in a system of free enterprise.

Intelligence, resourcefulness and daring, these are the only weapons we need.

With them, office boys have become business leaders, poor boys have grown to be millionaires, unknowns have risen to positions of great fame.

Free enterprise is more than a system of unfettered opportunity. It is a means of encouraging individual development — it is the lifeline to our national progress.

Without free enterprise, the restless striving of the ambitious becomes the restive resentment of the frustrated. And that leads to anarchy and chaos.

Sherron Electronics
W2XDK

SHERRON ELECTRONICS CO.
Division of Sherron Metallic Corporation
1201 FLUSHING AVENUE • BROOKLYN 6, NEW YORK

ANUFACTURERS OF ELECTRONIC DEVICES AND SHEET METAL FABRICATION

SPEED CONTROL SYSTEMS FOR HIGH-SPEED SQUIRREL-CAGE MOTORS

All utilize the principle of converting the frequency of the power supply to values above that of the commercial source and enable speed to be changed smoothly, over as much as a 40 to 1 range. Methods of frequency regulation

By G. W. HEUMANN
Administrative Assistant, Control Engineering Division
Apparatus Department, General Electric Company

EVERY branch of industry makes use of motorized drives requiring control of the motor speed. D-c motors of the shunt, compound, or series type, and wound-rotor induction motors may be used; and numerous systems of control are available from which may be selected the most suitable for a given application.

Considerations of mechanical design limit the speed for which motors with commutators or slip rings can be built, and 3600 rpm is about the top speed for which the use of conventional adjustable-speed motors is practicable.

Squirrel-cage Motors for Higher Speeds

Squirrel-cage induction motors, requiring no external connections to their rotors, can be built for speeds greatly in excess of those attainable with other types of motors. For high-speed applications, requiring speeds of thousands or even ten thousands of rpm, squirrel-cage induction motors have been built successfully. Some of the earliest applications of high-speed squirrel-cage motors were found in the machine-tool industry for powering the spindles of woodworking machines.

In many cases, speed control is not required. Since the speed of squirrel-cage induction motors is determined by the applied frequency and the number of poles of the motor, they are inherently constant-speed motors. The variation in speed between no-load and full load is small, amounting to only a few per cent. The only practical method by which the speed of squirrel-cage motors can be adjusted over a wide range is by adjusting the frequency of the applied primary power.

Although 3600 rpm is the highest synchronous speed which can be attained by two-pole motors connected to a commercial 60-cycle power system, higher speeds have been obtained by increasing the primary frequency applied to the motor above 60 cycles. Motors operating on a power system frequency of 1330 cycles have been built for speeds up to 80,000 rpm.

Frequencies above commercial frequencies are obtained by power-conversion equipment, in which power is taken from a constant-frequency power system and converted to a higher frequency. Frequency converters and synchronous alternators, driven by adjustable-speed motors, are the two fundamental types of conversion apparatus in use. Control of the adjusta frequency power output, which is tantamount to control of the speed of squirrel-cage motors connec to it, is accomplished by control of the speed of conversion equipment.

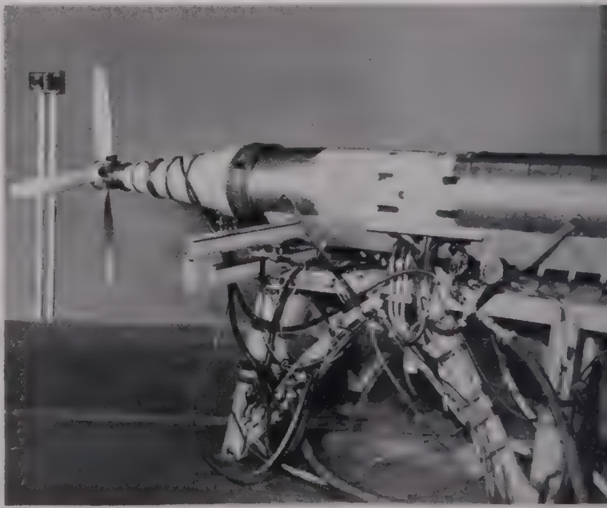
Particular woodworking-machine applications requ speed adjustment over a certain range, but it is necessary to maintain speed accurately over the l range. Conversion sets may then be driven by conv tional adjustable-speed d-c motors having a speed ra commensurate with the required frequency ra Speed control is accomplished by adjusting the mo shunt field, and the natural speed variation of the motor plus the slip of the squirrel-cage motor de mine the total variation in speed of the driven mach under load.

Where Speed Control Is Required

In recent years, high-speed squirrel-cage mo have been applied successfully to testing equipme requiring that speed be not only adjusted but maintained accurately over a wide range in load. T means that the power-conversion equipment has to equipped with regulating means to adjust and main frequency accurately over the rated frequency and l range.

Motors similar to the one shown in **Fig. 1** have b used for driving the fans of small high-velocity w

Fig. 1. Two 375-hp dual rotation motors for testing contra-turning prope mounted on torque stand *(Courtesy United Aircraft C*



This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 28 to 34.—Ed.

nnels, for testing superchargers, high-speed comessors, and gas turbines, just to name a few of the plications that high-speed squirrel-cage motors have nd for testing work.

The high-speed adjustable-speed motor in **Fig. 2**, ted 200 hp at 5000 rpm, is used for driving airplane st models in wind tunnels (**Fig. 3**). Such tests require at propeller speeds be maintained accurately and levels that are much higher than those of the actual ane. Engine performance can be predicted from conusions drawn on speed and motor-power-input measements.

sic Considerations

Since the problem of speed control of squirrel-cage otors is solved by speed control of the frequency-nversion sets, it is possible to build into the frequency-ntrol system all the refinements which have been deloped for motor-speed control of conventional drives.

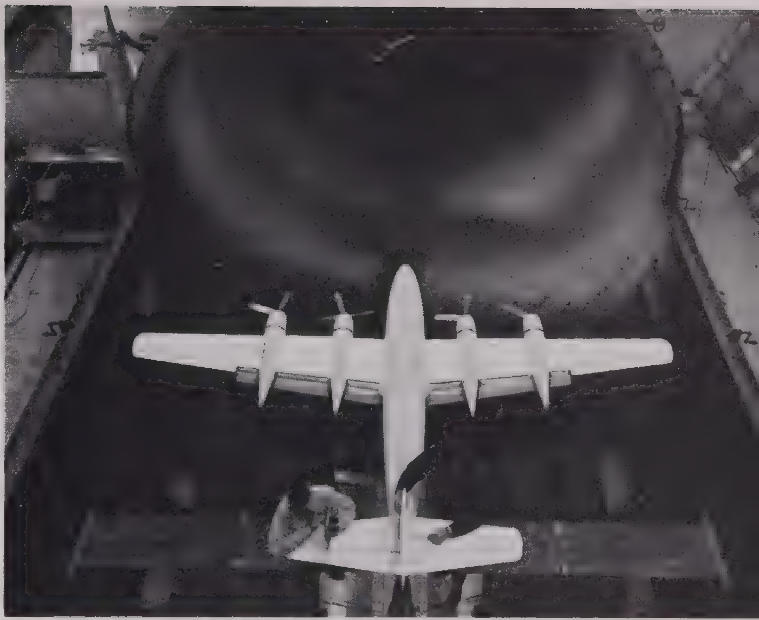
Because the d-c shunt motor can be built for a wide eed range and permits accurate regulation of the ljusted speed over the rated load range, the adjustable-eed d-c shunt motor with adjustable-voltage control widely used in adjustable-frequency control systems. aintaining the shunt-field excitation of the d-c motor d varying its armature voltage obtains speed control th constant torque over a range of approximately 10 1, and the kilowatt output of the adjustable-freency system varies proportionately to frequency.

ig. 2. Typical high-speed squirrel-cage motor rated 200 hp at 5000 rpm

The range of speed control can be extended by a rther 4-to-1 ratio by weakening the field of the c motor with maximum armature voltage held conant. The drive system produces constant horsepower thin the field-weakening range; thus the kilowatt tput of the adjustable-frequency systems stays conant for this range.

Control of the output voltage of the adjustable-freency system is quite important. To operate the uirrel-cage motor at its highest efficiency and with inimum heating, the airgap flux of the motor should maintained constant over the frequency range. Since e torque produced is determined by the airgap flux d the rotor current, the voltage applied to the motor ator terminals should change in proportion to the equency. For this reason, high-speed squirrel-cage otors are usually rated in volts per cycle.

In testing work, motors of different size and manufacre may have to be operated from a given adjustable-equency system. To enable these motors to develop eir full rated torque, the volts per cycle of the system ould be adjustable, and voltage drifts of the system should be minimized. Thus, a complete adjustable-frequency system should make provision to adjust volts per cycle over the range for which the system is designed and to regulate the system to the set value over the frequency and load range.



(Courtesy National Advisory Committee for Aeronautics, Langley Memorial Aeronautical Laboratory)

Fig. 3. Model of four-engine plane being set up for test in a wind tunnel, with propellers driven by high-speed squirrel-cage motors

Induction Frequency Converters

Induction frequency converters are essentially the same type of machines as wound-rotor induction motors. They contain a distributed phase winding on the stator and a distributed phase winding on the rotor, terminated at slip rings. Either the stator or the rotor may be the primary, which is connected to a commercial power system of constant frequency. For machine design reasons, large converters are generally built so that the rotor winding is the primary, and the adjustable-frequency power is taken off the stator terminals.

At standstill, the converter acts as a transformer, and secondary frequency is equal to primary frequency. If the converter rotor is driven in the same direction as flux rotation, the secondary frequency is reduced to zero at synchronous speed. At speeds above synchronism the frequency rises again, but phase rotation of secondary voltage is opposite to phase rotation of primary voltage. On the other hand, if the converter is driven in a direction against flux rotation, the secondary frequency rises above primary frequency. At synchronous speed, secondary frequency equals twice primary frequency; at twice synchronous speed, secondary frequency equals three times primary frequency; and at x times synchronous speed, secondary frequency equals $(x+1)$ times primary frequency.

The relationship between frequency and converter speed is illustrated in **Fig. 4**. The ratio of secondary frequency F_2 to primary frequency F_1 is plotted vs. the ratio of actual converter speed n to its synchronous speed n_s at primary frequency.

With the converter at standstill and the secondary open-circuited, the secondary voltage equals the primary voltage times the turn ratio of the converter windings. If it were possible to build a converter with no losses, at any frequency the secondary voltage would

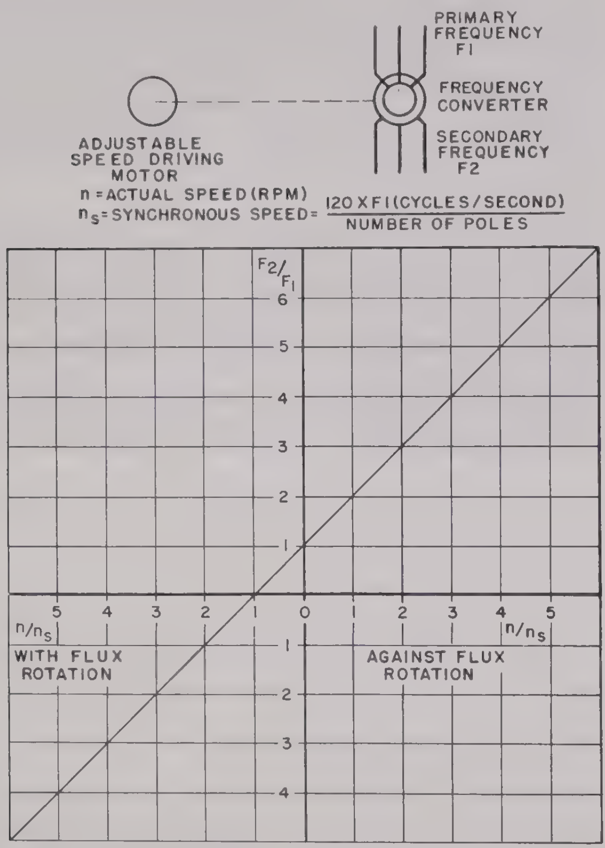


Fig. 4. Secondary frequency vs. speed of induction frequency converter

be equal to the standstill voltage times the ratio of secondary to primary frequency. Because of the unavoidable electrical losses in the converter, this relationship is not maintained over the frequency and load range. Thus, to obtain constant volts per cycle on the secondary side of the converter, it is necessary to provide an adjustable-voltage power source for the converter primary.

Frequency-converter Sets

Fig. 5 is an elementary diagram of the principal circuits of an adjustable-frequency system utilizing a frequency-converter set. The system is self-contained and requires only a commercial constant-frequency system as a power source.

Power is taken from the constant-frequency a-c system by the constant-speed set consisting of a driving motor, a d-c shunt generator, and a synchronous alt nator. The adjustable-speed set consists of an adju able-speed d-c shunt motor and the frequency convert The speed of the converter set is varied by varying voltage of the d-c generator.

The frequency converter primary winding is c nected to the alternator. To avoid drifts in prim frequency due to load changes, it is preferable to dr the constant-speed set by a synchronous motor. T circuit breaker for de-energizing the adjustable-f quency system is placed in the line between alternator and the converter, so that standard comm cial switching apparatus may be used.

For control and regulation, an auxiliary exciter se provided which consists of an a-c driving motor constant-voltage exciter providing a regulated cont bus, a voltage-control amplidyne, and a speed-cont amplidyne.

Speed of the adjustable-speed set (equivalent frequency of the secondary a-c system) is control by the frequency regulator, which acts on the fields the speed-control amplidyne supplying excitation to d-c shunt generator. A tachometer generator on adjustable-speed set produces a voltage signal prop tional to converter speed.

An identical tachometer generator, driven by a sm synchronous motor from the primary system, produ a voltage signal proportional to primary frequen Connecting the two tachometers in series obtain voltage signal proportional to secondary frequency.

This signal is fed into the frequency regulator a compared to a voltage set on the frequency-adjust rheostat. Any deviation of the secondary freque

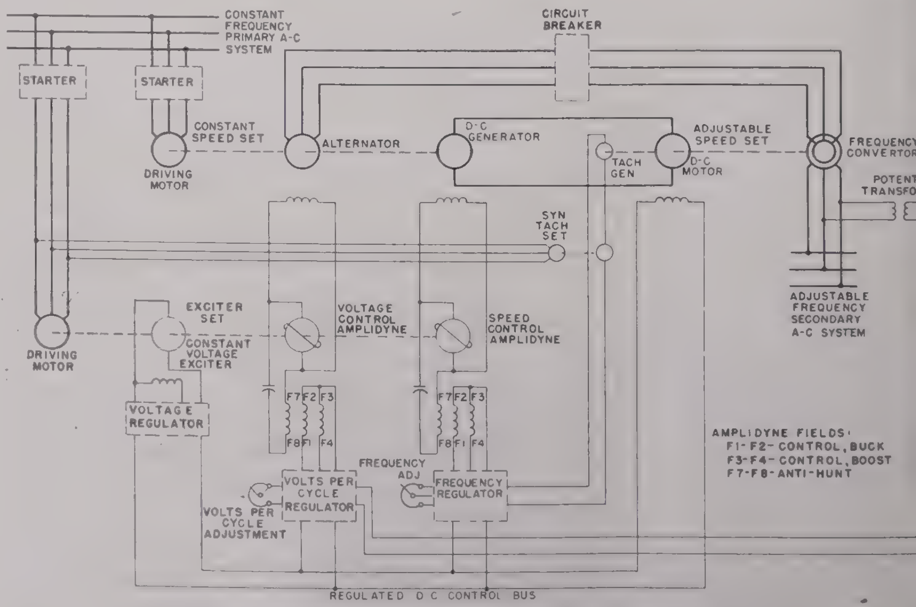


Fig. 5. Adjustable-frequency control system with induction frequency converter

from the set value causes a corrective change in generator excitation, resulting in a converter sp change.

Although this system maintains constant excitat on the d-c motor, it would be possible to extend verter set speed range by an additional amplidyne ing on the motor field. Up to base speed of the d-c tor, the frequency regulator would maintain con- nt d-c motor field and regulate d-c generator field. the range beyond base speed, the regulator would intain maximum d-c generator voltage and regulate motor field current.

Volts per cycle is controlled by the volts-per-cycle gulator acting on the fields of the voltage-control plidyne which supplies excitation to the alternator. voltage signal is obtained from the frequency con- rter secondary lines and fed into the regulator, which justs alternator excitation to maintain secondary lts per cycle at the value set on the volts-per-cycle justment.

quency Regulator

Three fields are used to control the output voltage the speed-control amplidyne. As shown in **Fig. 5**, boost field *F3-F4* is connected to the regulated control bus and contributes a constant mmf in the ection to raise the generator voltage. The buck field *-F2* opposes the boost field. Its mmf is so regulated at the difference in mmf of the two fields produces amplidyne output voltage commensurate with the sired converter speed.

Antihunt field *F7-F8* is connected to the amplidyne tput circuit through a capacitor. Thus the mmf ntributed by the antihunt field is proportional to the e of change of amplidyne output voltage, and its larity is such as to oppose any change in amplidyne ltage.

Fig. 6 shows in elementary form the principal cir- its of the frequency regulator, which, in addition to eed control, also includes current-limit control. During celeration and deceleration, which might be effected rapidly turning the frequency-adjustment rheostat, d-c motor armature current must be limited to a agnitude which can be commutated safely by the machines.

A potentiometer for frequency adjustment is con- cted across the regulated d-c control bus *1-2*, and voltage tapped off by the slider determines the sired frequency. The frequency signal from the chometer generators is loaded into a resistor and lanced against the voltage tapped off by the slider. e difference between actual and desired frequency termines the potential of grid point *3* of tube *1* and nsequently the current passed by tube *1*, which in rn determines the potential of plate point *4*. Disre- rding tubes *3* and *4* for the moment, grid point *5* of be *2* swings the same way as point *4*, thereby affect- g the current passed by tube *2*, which excites buck ld *F1-F2* of the amplidyne.

When the frequency-adjustment rheostat is turned call for higher frequency, the voltage to the slider no longer balanced by the tachometer voltage. Point becomes more positive; tube *1* passes more current; ints *4* and *5* become more negative; and consequently be *2* passes less current. As a result, field *F1-F2* becomes weaker; the amplidyne voltage rises; and the d-c motor speed increases until a balance is re-established between actual frequency and the set value.

Tubes *3* and *4* are used for current-limit control, superimposed on frequency control. Their control grids are connected to a potentiometer, the voltage of which is proportional to the drop across the commutating fields of the d-c motor and generator.

This drop is a measure of the current flowing in the d-c armature loop circuit, which is proportional to kilowatt load on the secondary system. Through a positive screen-grid bias, tubes *3* and *4* are so adjusted that, with no current flowing in the loop circuit, tube *3* is turned off and tube *4* is fully conducting. With normal current flowing in the loop circuit in the direction of the arrow, point *6* is negative with respect to point *2*. When the loop-circuit current during acceleration approaches the commutating limit, point *6*, and likewise grid point *7* of tube *4*, reach such a negative value that tube *4* passes less current; point *5* becomes more positive; tube *2* passes more current than the frequency adjustment calls for; and the motor speed rises more slowly. Tube *4* thereby prevents too rapid acceleration. Tube *3* is not affected, since it is already turned off.

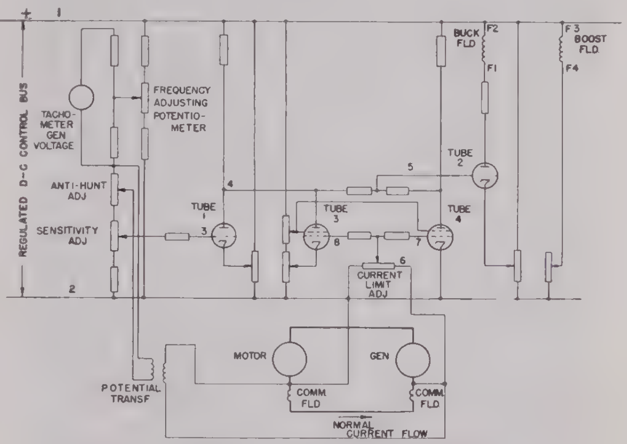


Fig. 6. Principal circuits of frequency regulator

Conversely, when the frequency-adjusting rheostat is turned to call for lower frequency, which is equivalent to retardation of the converter set, the loop-circuit current reverses. As a result, point *6* becomes more positive than point *2*, and likewise the potential of points *7* and *8* rises. This has no effect on tube *4*, which is already turned on. However, tube *3* will start conducting when the loop-circuit current approaches the commutating limit. Point *5* becomes more negative, and tube *2* carries less current than the frequency adjustment calls for, so that the d-c motor speed is reduced more slowly. Tube *3* thereby prevents too rapid retardation.

A potential transformer, the primary of which is connected across the commutating fields, provides an antihunt feature. A voltage is thus induced in the transformer secondary to oppose a generator voltage change, the magnitude of the induced voltage being proportional to the rate of change of the load current. This voltage is introduced in the frequency-adjusting circuit, thus affecting the potential of point *3*.

A typical frequency regulator, with cover removed, is shown in **Fig. 7**. The cover is hinged, permitting easy access to the antihunt transformer, the tubes, and the potentiometers for antihunt, sensitivity, and bias adjustment. Only two tubes appear in the view, because tubes *1* and *2*, and also tubes *3* and *4*, in **Fig. 6**, are contained in a common envelope.

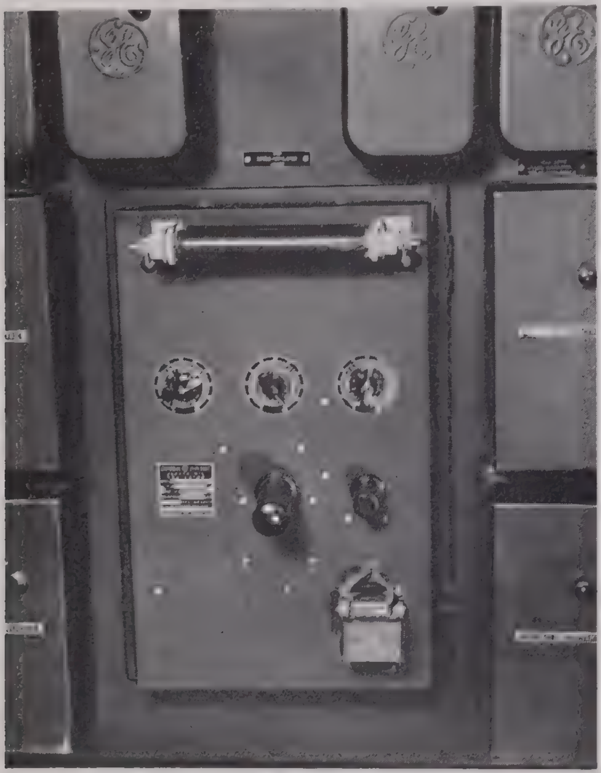


Fig. 7. Typical frequency regulator with cover removed. The loading resistor for the tachometer output is shown at the top. The frequency-adjusting rheostat is remotely mounted on a console from which the operator controls and supervises the equipment

To prevent burning of the slip rings, converters should not be permitted to carry load at standstill. The frequency regulator should be so adjusted that the minimum speed of the converter never reaches zero.

Volts-per-cycle Regulator

Details of the volts-per-cycle regulator and the connections of the voltage-control amplidyne are indicated in **Figs. 8** and **9**. Referring to **Fig. 8**, the voltage signal from the adjustable-frequency system, appearing across the secondary of the potential transformer, is rectified and impressed on amplidyne field *F3-F4*. Field *F1-F2* is connected to the same voltage source, but with opposite polarity. In series with the *F1-F2* field circuit there is connected an adjustable reactor, wound as a toroid with a sliding contact with which various numbers of turns can be tapped off. This reactor is saturable, and consequently the current through *F1-F2* is not proportional to the frequency converter secondary voltage. The adjustable reactor is used by the operator to set the desired volts per cycle.

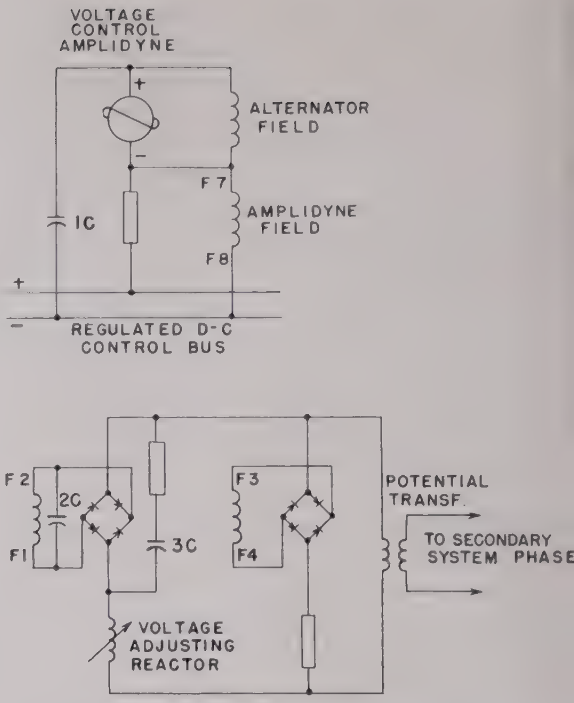

VOLTAGE CONTROL AMPLIDYNE
+
−
ALTERNATOR FIELD
F7
AMPLIDYNE FIELD
F8
1C
+
−
REGULATED D-C CONTROL BUS
F2
2C
F1
3C
F3
F4
POTENTIAL TRANSF.
TO SECONDARY SYSTEM PHASE
VOLTAGE ADJUSTING REACTOR

Fig. 8. Principal circuits of the volts-per-cycle regulator

The amplidyne field *F7-F8* is connected thro capacitor *1C* to the amplidyne output terminals that it acts as an antihunt field. It is also conne to the regulated d-c control bus, so that it contrib a fixed mmf to the total amplidyne excitation.

The operation of the regulator will be fur described with reference to **Fig. 9**. As the altern voltage, determining the converter secondary quency, is solely a function of the excitation supp by the voltage-control amplidyne, converter secon voltage is plotted vs. amplidyne mmf, which ca expressed as the sum of the ampere-turns of the var

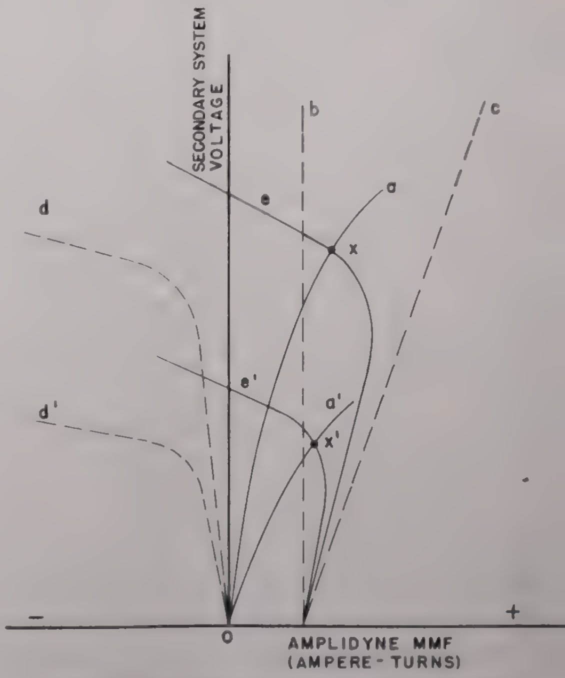


Fig. 9. Mmf diagram for the volts-per-cycle regulator

fields. Curve *a* represents the secondary voltage of the converter at a given frequency. Line *b* is the mmf of field *F7-F8* (**Fig. 8**), which is constant. Line *c* represents the mmf of field *F3-F4* which is proportional to converter secondary voltage. Curve *d* represents the mmf of field *F1-F2*. However, as the voltage rises, the reactor saturates; its reactance drops sharply; and the mmf rises much faster than the voltage. Curve *e* is the composite of curve *c* and curve *d*—that is, the net mmf of the amplidyne. The operating point *x* lies at the intersection of curves *a* and *e*.

When the frequency is changed—at half frequency, for example—the converter secondary voltage is expressed by curve *a′*. Line *c* remains unchanged as the mmf of fields *F3-F4* and *F7-F8* does not change with frequency. The mmf of field *F1-F2* becomes *d′* because of the changed reactance of the reactor.

At halved frequency, the net mmf of the amplidyne follows curve *e′*, and the new operating point is *x′*. Since voltage at *x′* is half of voltage *x*, volts per cycle are the same. With proper selection of components comprising the regulator, volts per cycle can be maintained over a wide range of frequencies.

A front view of a typical volts-per-cycle regulator, with cover removed, is shown in **Fig. 10**. Remotely mounted on the control console is the saturable reactor used for voltage adjustment.

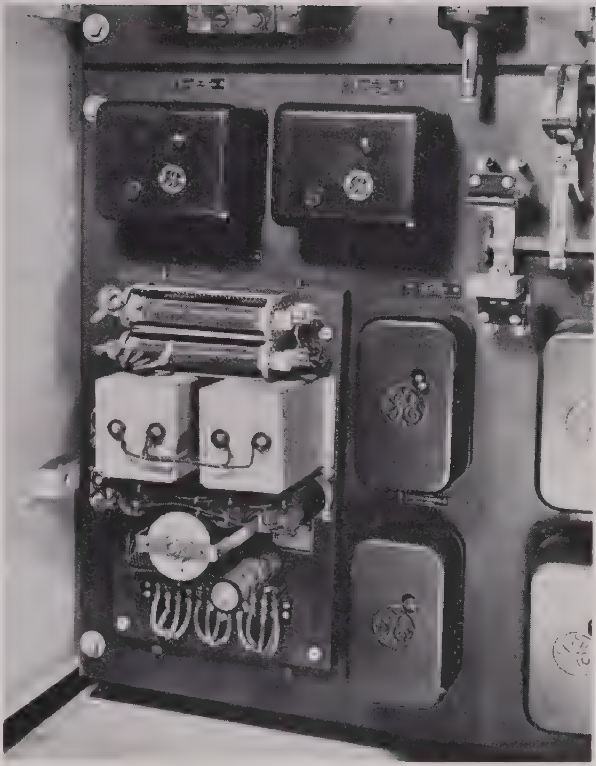


Fig. 10. Typical volts-per-cycle regulator

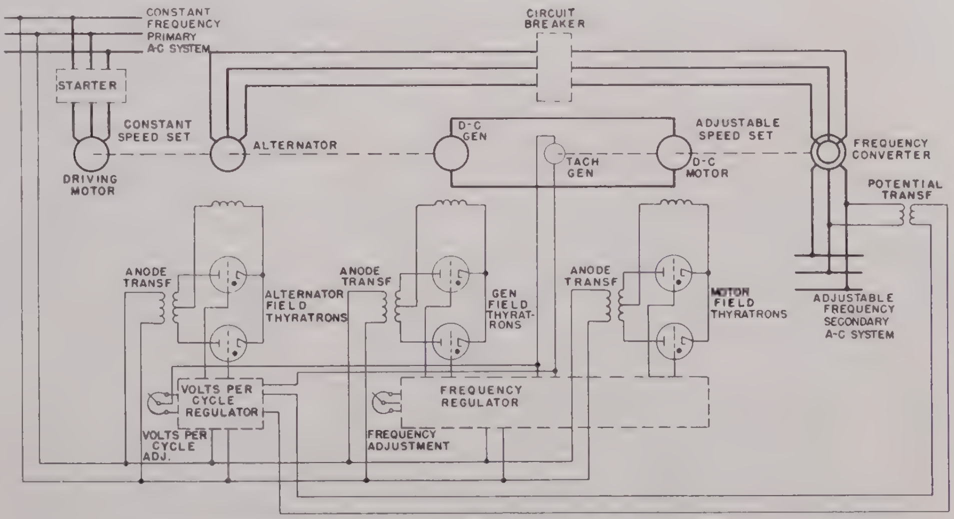


Fig. 11. Adjustable-frequency-control system with induction frequency converter and thyratron exciters

Electronic Exciter System

Frequency-converter systems have been built using thyratron tubes for exciting the fields of the d-c machines and the alternator, thereby eliminating the auxiliary exciter sets. **Fig. 11** shows the principal circuits of such a system. Thyratron tubes, connected to the a-c power supply as biphase half-wave rectifiers, supply d-c excitation to the fields of the d-c generator, the d-c motor, and the alternator. The field current of the rotating machines is varied by grid control of the thyratrons, varying the firing angle and consequently the average d-c current flowing through the tubes. Electronic regulators containing high-vacuum tubes are used to control the thyratron grids.

A tachometer generator mounted on the converter set obtains a signal proportional to secondary frequency. This signal is fed into the frequency regulator and compared to a reference which is the drop across a portion of the frequency-adjustment potentiometer, which represents the desired frequency. The regulator first acts on the d-c generator field and maintains constant motor-field excitation. If the equipment is designed for operation above base speed of the d-c motor, the regulator acts on the motor field in the field-weakening range, while maintaining maximum generator voltage.

Only output frequencies above that of the supply frequency of the primary are provided in this system, since rotation occurs in one direction only. If operation with secondary frequencies down to zero is required, either an additional thyratron rectifier for field reversal must be included, or provision must be made to reverse the phase rotation between the alternator and the converter primary.

The volts-per-cycle regulator obtains two signals: a voltage signal from the converter secondary lines, and a frequency signal from the tachometer generator. The desired volts per cycle is set on a potentiometer acting as a reference, and, through thyratron grid control, the alternator excitation is so adjusted as to maintain constant volts per cycle on the adjustable-frequency system.

Parallel Operation of Converters

When an adjustable-frequency system is designed for testing work, its capacity must take into consideration the largest load which it may be called upon to deliver. Much of the testing work, however, generally utilizes only a portion of that maximum capacity.

Greater flexibility and better utilization of the equipment is obtained by installing several equipments, each feeding its own adjustable-frequency network. Generally, several tests can be performed at the same time, each test utilizing one converter equipment. For those tests which require the total output of the system, several converters can be operated in parallel.

Frequency converters, being induction-type machines, can be synchronized without the aid of special synchronizing equipment, in much the same manner as power selsyns. The converter sets are started at low speed. With converter primaries open, their secondaries are tied together. Two primary lines are then closed to all converters, thereby applying single-phase excitation and locking the machines in step. As a final step, the third lines are closed and the converters are ready to take load.

Provision must be made in the control equipment to insure that the converters share the load evenly during parallel operation. The frequency regulators and volts-per-cycle regulators are connected in parallel and respond to the adjustments of one set which acts as a master.

To prevent overheating of any machine, the kilowatt-power and the kilovar-power contributed by each converter to the secondary system must be equalized. The drops across the commutating fields of the d-c machines of each set, which are a measure of shaft torque and kilowatt load on each converter, are compared. Any difference acts on the frequency regulators to equalize the load. The primary currents of the converters, which are a measure of the excitation and kilovar load on each converter, are also compared, and any difference acts on the volts-per-cycle regulators to equalize the kilovar load.

Synchronous Alternator Sets

In place of frequency converters, synchronous alternators may be used as a source of adjustable-frequency power. **Fig. 12** is an elementary diagram of the principal circuits of an adjustable-frequen control system utilizing an alternator. This diagram similar to **Fig. 5**. There is one less machine on t constant-speed set. The frequency regulator respon to the signal from only one tachometer generator the adjustable-speed set, because secondary frequen is directly proportional to alternator speed.

The voltage-control amplidyne supplies field excit tion to the alternator, and the volts-per-cycle reg lator obtains its signal from two of the alternat lines. The circuit breaker for power switching connected in the secondary-frequency line from t alternator.

Because the exact speed of the constant-speed s has no effect on the frequency of the secondary syste this set may be driven either by a synchronous or induction motor.

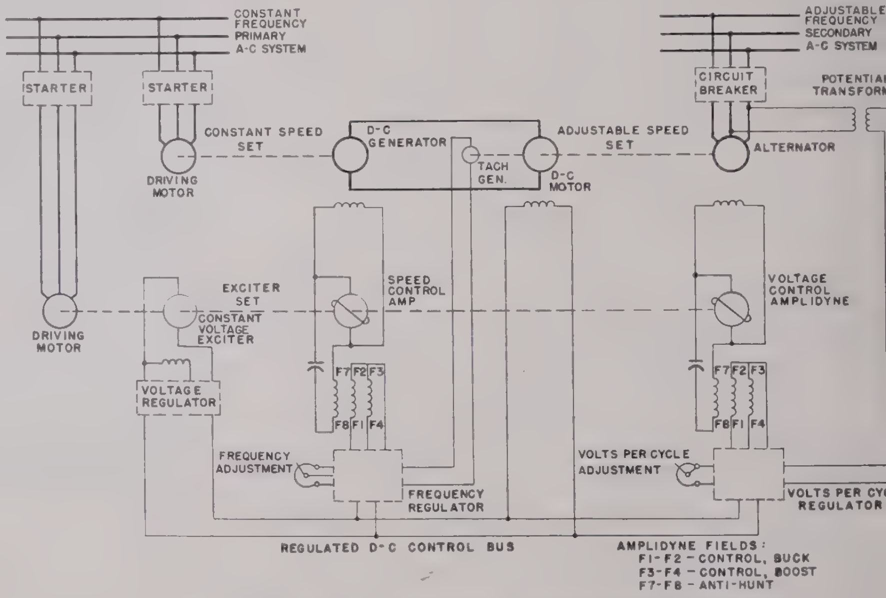


Fig. 12. Adjustable-frequency-control system with adjustable-speed alternator

The system as shown in **Fig. 12** maintains consta d-c motor field and controls secondary frequency on by field control of the d-c generator, the seconda system output power being proportional to frequenc If desired, d-c motor-field-weakening control may added, and in this range the secondary-system outp power is constant.

Converter or Alternator

A comparison between **Fig. 5** and **Fig. 12** indicat that one less rotating machine is required for alternat sets than for frequency-converter sets. To what exte this becomes an economic factor is determined by t desired frequency range, because for a given maximu secondary frequency, the converter set operates at lower speed than the alternator set, and the spe range of the d-c machines affects their cost.

Advantages of frequency converters, being asy chronous machines, are their high overload capacit stability, and the ease with which several sets can operated in parallel.

GASEOUS INSULATION FOR HIGH-VOLTAGE APPARATUS

Guglielmo Camilli

Investigations reveal that sulphur hexafluoride possesses superior insulating qualities, even at pressures of one, two, and three atmospheres

John J. Chapman

By G. CAMILLI and J. J. CHAPMAN
Pittsfield Works, General Electric Company

THIS article describes how a group of halogenated gaseous compounds were investigated to determine their impulse (1½×40 microecond wave) and 60-cycle strength in uniform and ıonuniform fields at pressures of one, two, and three .tmospheres. The scope of this investigation was conined to bare electrodes; additional testing will be equired to determine the behavior of these gases with 'arious types of solid insulation.

It has been found that sulphur hexafluoride (SF_6) ıossesses superior insulating properties for high-voltage :pparatus, even at these relatively low pressures. Data ıbtained in an approximately uniform field indicate hat at 30 lb gage pressure the impulse strength of this as approaches that of oil. Therefore, certain classes of iigh-voltage apparatus may advantageously use this as for their insulation, if other properties are adequate.

In recent years several articles have been presented n technical literature on the dielectric behavior of ompressed gases. The fact that the dielectric strength f gases under certain special conditions can be superior o either liquid or solid insulating materials makes them ery promising insulating media and has attracted the ttention of many investigators.

Compressed air and nitrogen have been used in recision capacitors where low dielectric loss is essential, nd compressed Freons have been used in x-ray transormers where reduced dimensions and nonflammability re of primary importance(1). In general, these appaatus have been operated indoors, where the ambient emperature does not drop to a very low value. For utdoor equipment, a gas should be selected that will ot require special heating auxiliaries to prevent conlensation at low ambient temperatures. Another very nportant requirement is that the gas have sufficient npulse strength to protect the apparatus from failure aused by lightning strokes on the transmission lines o which the apparatus is connected.

ondensation of Gases

The outdoor problem of condensation at low ambient emperatures obtains a ready solution from the gas SF_6 and will therefore be considered first. In **Fig. 1**, the saturated vapor pressure curves of three gases (SF_6, Freon 22, and Freon 12) are shown. A gas cannot be operated at a pressure higher than its vapor pressure corresponding to the temperature under consideration. If the pressure were increased above the vapor pressure, the extra vapor would probably condense.

The curves shown in **Fig. 1** indicate that sulphur hexafluoride can be operated at higher pressures than either Freon 12 or Freon 22. As an example, assume that a given apparatus is filled with Freon 22 at a gage pressure of 150 lb per sq in. at a temperature of 40 C (Point *A*). Also, impose the condition that the total quantity of gas in the system is unchanged. If the temperature of the vapor is lowered from its initial value at *A*, the pressure will drop to some value at *B* where saturation conditions take place. Over this interval from *A* to *B* the dielectric strength of the apparatus will remain virtually unchanged, because the pressure decreases as in a perfect gas, following the change in absolute temperature. However, any further decrease in temperature will result in condensation and

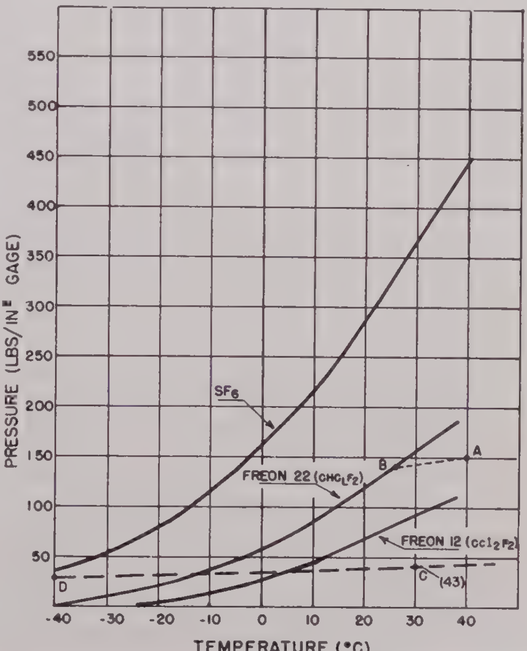


Fig. 1. Saturated vapor-pressure characteristics of sulphur hexafluoride, Freon 22, and Freon 12

---

(1)"Dielectric Strength of Insulating Materials" by E. E. Charlton and . S. Cooper, GENERAL ELECTRIC REVIEW, September, 1937, p. 438.

This article was presented by the authors as a paper at the AIEE Midwest eneral meeting at Chicago, November 3, 1947.

This article is so paged that, without mutilating other articles, it can be onveniently removed for separate filing by tearing out pages 35 to 41.—ED.

the pressure will follow the vapor-pressure curve shown in **Fig. 1**. With many gases the dielectric strength very closely depends upon the absolute pressure; thus the dielectric strength may be expected to follow a curve similar to the temperature-pressure curve in **Fig. 1**.

In the case of SF_6, however, a gage pressure of only 43 lb per sq in. at 30 C might be considered a suitable operating condition because of the high dielectric strength of this gas. At a temperature of −40 C, the gage pressure would be 30 lb per sq in., having followed the path *CD* shown in **Fig. 1**. In going from point *C* to point *D*, the SF_6 vapor-pressure curve has not been intercepted, so no condensation will result. **Fig. 2** illustrates experimental proof that SF_6 behaves as a perfect gas over a wide region of practical application.

Basic Concepts in Breakdown of Gases(2)

The electron was early regarded as the initiating agent in the dielectric breakdown of gases. In traveling through a gas under the action of an accelerating field *F*, the electron is able to create new electrons by disruption of gas molecules upon collision. If electrons be liberated from a plate in a rarefied gas, the current which they carry from this plate to one parallel to it is a function of the voltage. As the voltage increases, at first the current follows in a nearly linear fashion. Eventually, it is believed to reach a constant or saturation value at i_0. As higher fields are applied, the apparent saturation gives place to a new, rapid increase of current with potential, the current eventually increasing exponentially in the form of a spark. At this field strength, the electrons are producing α new pairs of ions per centimeter of path due to collisions with the molecules of gas. The current increases with distance in gas according to law

$$i = i_0 \epsilon^{\alpha x}$$

where α = pairs of ions produced per centimeter
x = the length of path in centimeters
i_0 = the initial current

The quantity α is a function of pressure p and the field strength F. It depends upon the ability of the electron to pick up energy from the field and the probability of its ionization once it has the energy. If E_0 is the required energy to produce ionization, this condition takes place when the electron is accelerated over the mean-free-path-distance λ_1 to such an extent that $F\epsilon\lambda_1 = E_0$. The mean-free-path distance is a function of pressure—that is, $\lambda_1 = \lambda_0\ p_0/p_1$. If λ_1 is decreased by raising the pressure, F must be correspondingly increased to cause the same degree of ionization.

Paschen discovered his famous law in 1889, namely $V_s = f(p\delta)$. Thus, the sparking voltage is a function of the product of pressure and distance. This law also followed from theoretical extensions of Townsend's theory. Experimental agreement is found with Paschen's law for gases in uniform fields. As the pressure is decreased, the breakdown voltage decreases in a regular manner until the gas is quite rare, and then the voltag rises again. The minimum breakdown voltage occur at the "critical pressure." Even in this region the la has been proved valid experimentally.

If spark breakdown is dependent upon a local concentration of ions or influenced by the presence o deficiency of ions in any region, then for this electrod arrangement in gas, the law will not be obeyed. Therefore, with gases or electrode configurations that mak space-charge concentrations possible before final breakdown, deviations from Paschen's law are to be expecte

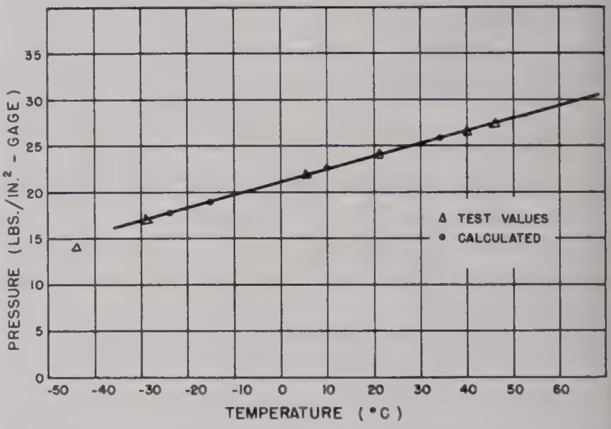


Fig. 2. Relation between pressure and temperature in a constant volume of SF_6 gas. Comparison between calculated and tested values

In the original work, Townsend elaborated upon th collision process and introduced an ionization coefficient for positive ions causing further ionization b collision. From later experiments it appears that th positive ions do not cause significant ionization due t their collision with molecules. However, positive io fields cause the creation of photons and attendan ionization. So the second Townsend coefficient fo positive ions has a place in modern physics, thoug quite different from the original intention.

Meek's theory of positive streamer propagation(suggests that the local field at the tip of the positiv space charge left in the wake of an electron avalanch must be commensurate with the applied field fo streamer propagation by photon processes. Since th shape and intensity of the streamer-tip field are dependent upon the mobility and diffusion characteristic of the gas, as well as the nature of the ions formed, it not surprising that pressure changes in complex gas result in anomalous breakdown behavior.

Apparatus for Testing

A gas cell shown in **Fig. 3** was developed for th purpose of making high-voltage breakdown tests o the following gases:

N_2
F-12 = $(C\ F_2\ Cl_2)$
F-13 = $(C\ F_3\ Cl)$
F-14 = $(C\ F_4)$
F-22 = $(C\ H\ Cl\ F_2)$
F-23 = $(C\ H\ F_3)$
SF_6

---

(2) Leonard B. Loeb and John M. Meek: *The Mechanism of the Electric Spark*, Stanford University Press, 1941.

The bottom electrode was a 1-in.-diam sphere at ound potential; the upper electrode was either a in.-diam sphere or a tungsten rod. The upper sphere as used for tests requiring a uniform field. The rod rovided an electrode for nonuniform gradients. This d was of 0.100-in. diam and was rounded on the end a 0.050-in. radius, thus providing a nonuniform field known configuration. The separation of electrodes uld be set accurately (within 0.0052 in.) without sing any gas pressure.

ethod of Making Tests

Since most of this test work was done during the war, alogenated gases were difficult to obtain, and small-olume testing became of paramount importance. About ve liters of gas were required to fill the cell, and tests uld be run up to 350 kv impulse. In a few cases external ashover required that the cell be immersed in oil.

After each gas was tested, the electrodes were lished, and the inside porcelain wall was washed ith soap and water and then with distilled water. ashing was quite necessary to remove the last traces the halogenated gases which would have interfered ith ensuing tests. After vacuum-drying procedure moved the last traces of moisture, a blank test was in with N_2 before admitting a new gas for test.

It was decided that the gases should first be evaluated cording to dielectric strength as determined by tests a uniform field. In the small volume used, the most tisfactory uniform field possible was that provided by o spherical electrodes 1 in. in diam and spaced 0.25 . apart.

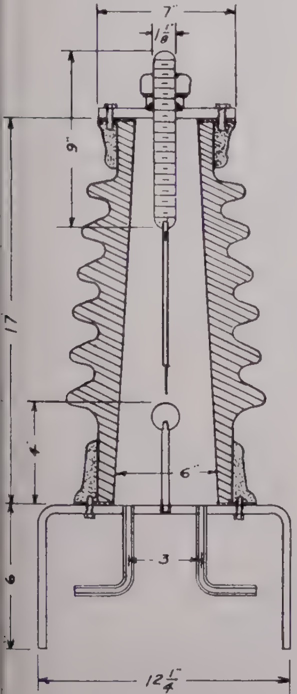


Fig. 3. Cross-section of the cell used for comparing the dielectric strength of several gases

After some preliminary testing with N_2 at 30 lb gage essure, it was found that positive and negative imlse breakdown values agreed within 10 to 15 per cent. his at least indicated a moderate degree of symmetry the electrodes and was accepted as the most ideal field possible in the small volume. It offered strikingly contrasting phenomena when compared to the tungsten rod-sphere type of configuration. This latter configuration was selected after preliminary investigation because "anomalous breakdown decrease with pressure" could then be demonstrated in a small volume of gas. Tests were made up to 2-in. spacing with this arrangement.

Both types of electrodes were employed with impulse and 60-cycle voltage at 0, 15, and 30 lb gage pressure. The center line of the electrode system was approximately three inches from the porcelain wall. However, high-voltage testing within a confined space seldom yields results identical with testing in unlimited space. The one-inch setting is considered the most reliable source of data with the nonuniform field arrangement and is therefore used as a point of comparison among the gases. The number of breakdowns for the halogenated gases was picked judiciously in order not to change the character of the electrodes before a refill, because repeated testing has been reported as a cause for surface change in electrodes.(3)(4) Since a large number of identical tungsten rods were available, frequent change, when convenient, was exercised, and no change in the character of the rounded end was observed. The test chamber, without windows, was completely closed. It is known that impulse breakdowns of air or nitrogen are affected by a closed vessel. This effect is shown in these tests, where the impulse ratio for nitrogen is 2.8, instead of 1 as would be expected from tests in open air.

Each interruption, planned or otherwise, causing a change of gas meant the loss of a small volume even when it could be withdrawn into a liquefaction cylinder. Fortunately, nitrogen is a common gas and was therefore ideal for the many blank tests that were necessary to check the cleanliness of the cell. The data (points) shown on the graphs represent an average of three trials. All of the Freon gases except F-14 invariably showed some carbon deposit when the cell was torn down preceding a refill; nitrogen and SF_6 showed no deposit.

A 500-kv Marx circuit was used for generating 1½× 40 microsecond impulse waves and breakdowns were observed with a cathode-ray oscillograph. Fractional parts of the capacitor bank were used to facilitate tests in the lower voltage range. Sixty-cycle breakdowns were accomplished with a 50-kv and a 150/300-kv cascade set. The wave form was close to sinusoidal, as indicated by rms and crest voltmeters.

Test Results

In **Fig. 4**, illustrating the 60-cycle breakdown in a uniform field at zero gage pressure (one atmosphere), the general superiority of the halogenated gases over nitrogen is illustrated, although at that particular pressure in the uniform field F-22 and F-14 have about the same value, with F-23 definitely lower than nitrogen. F-12 and SF_6 are definitely superior to N_2 and may be considered to have approximately the same

---

(3) "Breakdown Studies in Compressed Gases" by A. H. Howell, *AIEE Trans.*, vol. 58, 1939, p. 192.

(4) "Electric Strength of Air at High Pressures," by H. H. Skilling and Wm. C. Brenner, *AIEE Trans.*, vol. 60, 1941, p. 112.

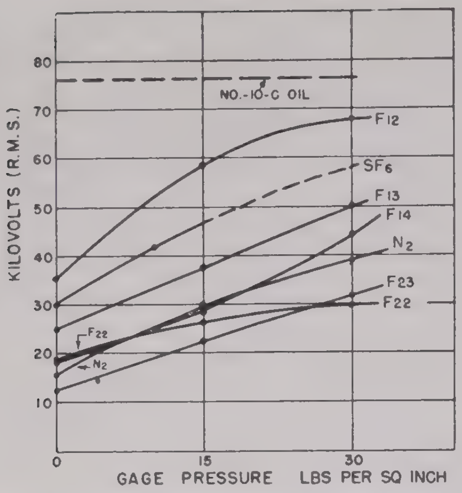


Fig. 4. Sixty-cycle dielectric strength of several gases and No. 10-C oil tested between two 1-in.-diam spheres spaced ¼ in. and at gage pressure up to 30 lb per sq in.

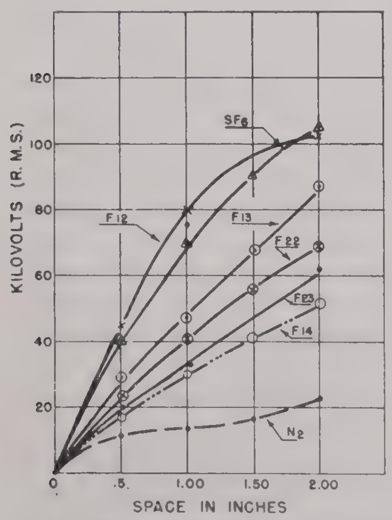


Fig. 5. Sixty-cycle dielectric strength of gases tested between tungsten rod and 1-in.-diam sphere at atmospheric pressure

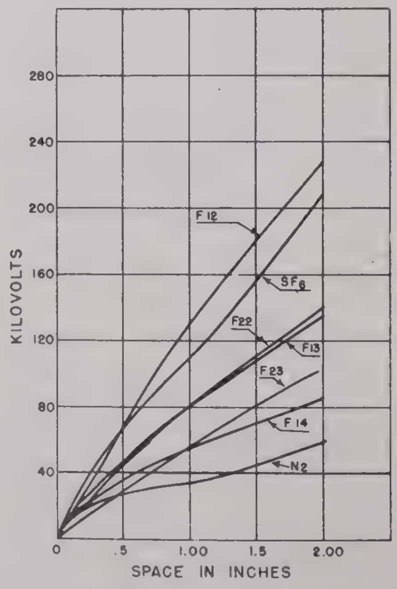


Fig. 6. Negative-impulse tests (1½ ×40 microsecond wave), at atmospheric pressure, of several gases tested between tungsten rod and 1-in.-diam sphere

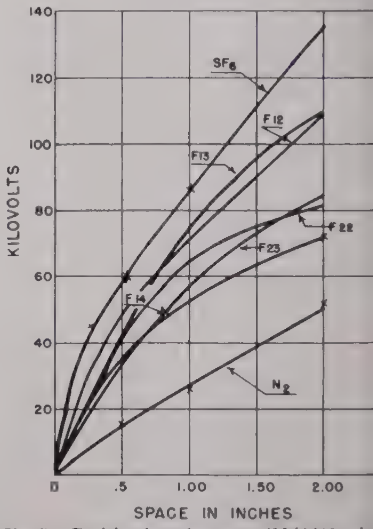


Fig. 7. Positive-impulse tests (1½ ×40 mic second wave), at atmospheric pressure, of seve gases tested between tungsten rod and 1-in.-di sphere

respective margin over air. This is of some interest because an increasing amount of equipment rated up to 15 kv now depends on air as an insulating and cooling medium at one atmosphere pressure. In **Figs. 5, 6,** and **7**, 60-cycle, negative-impulse and positive-impulse breakdowns are shown as a function of spacing in a nonuniform test field at atmospheric pressure. Here again, SF_6 and F-12 show marked superiority over nitrogen and consequently over air, which is known to have closely the same breakdown values as nitrogen. On this basis it is apparent that using SF_6 or F-12 will allow the extension of gas-filled apparatus. SF_6 could be used for temperatures as low as −40 C in such an application, but F-12 would begin to liquefy at −20 C, thus limiting its usefulness for wide application.

In **Figs. 5, 6,** and **7**, it is shown that in the nonuniform field at one atmosphere pressure SF_6 is 2.8 to 5 times as strong as N_2, depending upon the type of breakdown. In the uniform field data in **Fig. 4**, the 60-cycle breakdown of SF_6 is approximately 1½ times that of N_2. Since the uniform field was within the confines of a small porcelain cell and utilized only ¼-in spacing, it was decided that some tests should be performed at a spacing of two inches, requiring higher tes voltages in the range of interest to design engineer This test setup is shown in **Fig. 8**; essentially it consist of two toroid electrodes looped through and placed a right angles to each other. Such a field configuratio would be practical in the design of some apparatu SF_6 is compared with air in **Fig. 9**; at one atmospher it is seen that SF_6 has 2.1 and 2.4 times the respectiv 60-cycle and impulse strength of air in the toroi electrode system. The test setup indicated in **Fig. 8** wa included in a porcelain shell of rather large diamete For this reason only the most promising halogenate gas (SF_6) was compared with air; this seemed advisab in view of the scarcity of Freons during the war.

In **Figs. 5, 6,** and **7**, the advantages of SF_6 ove nitrogen in a nonuniform field are very pronounce Such a field is avoided wherever possible in design apparatus, but sometimes only a compromise is possibl A distortion of the field is always associated wit boundary surfaces between the gas and solid insulati barriers, wire insulation, and insulated supporti structures. An isolated winding or a bushing groun

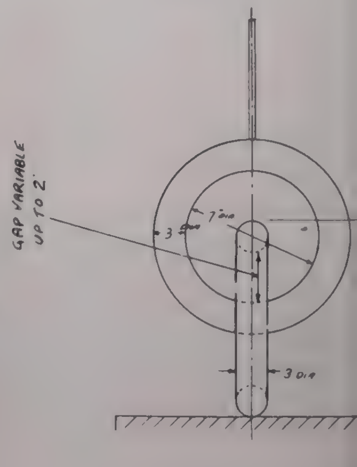


Fig. 8. Test set-up to obtain data at large gap spacings

eeve or tank part may provide the most sharply ırved electrode. For this reason, both polarities of npulse test are of importance in evaluating the per-rmance of a gas in a nonuniform field. Positive-npulse polarity applied to the electrodes of sharper rofile renders lower breakdown values for gases than oes the application of negative-impulse polarity.

In the consideration of results thus far, the advan-ages over air or nitrogen at atmospheric pressure have een emphasized because this pressure offers a promis-g field of application. As the pressure is increased, ome of these gases show even more pronounced dvantages over nitrogen. Therefore, another question posed: are any of the gases suitable for replacing oil some high-voltage apparatus?

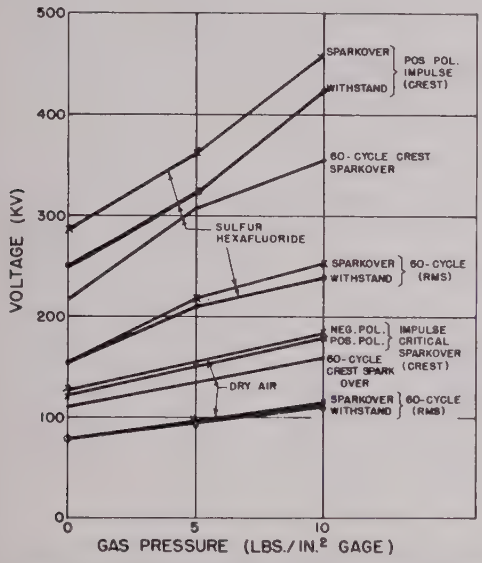


Fig. 9. Impulse and 60-cycle sparkover and withstand voltages of SF_6 and air, using 2-in. gap spacing in the test arrangement shown in Fig. 8

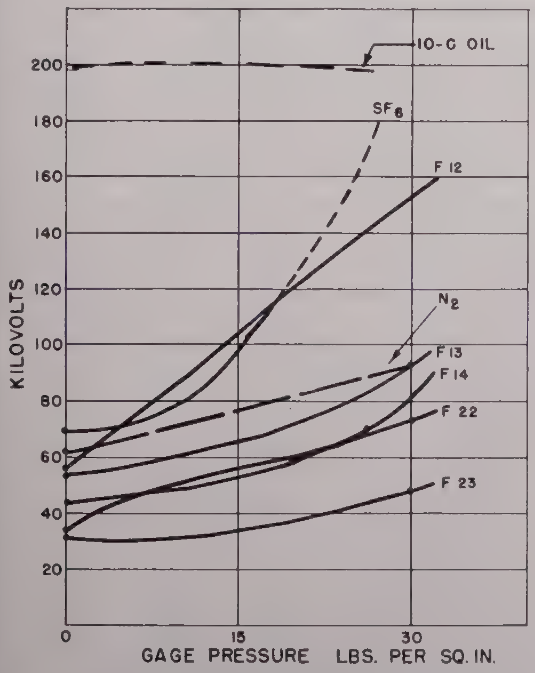


Fig. 10. Impulse dielectric strength of gases. Test made between two 1-in.-diam spheres spaced ¼ in. at gage pressure up to 30 lb per sq in.

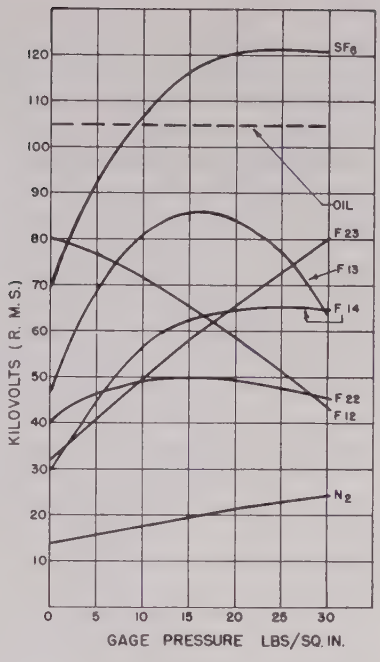


Fig. 11. Sixty-cycle dielectric strength of several gases. Tests made between tungsten rod and 1-in.-diam sphere spaced 1-in. Values for No. 10-C oil are also shown

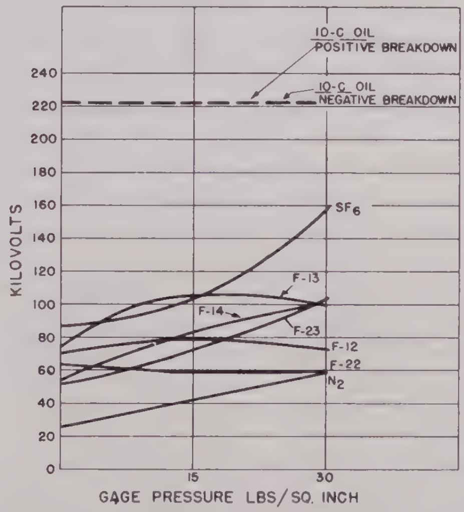


Fig. 12. Impulse dielectric strength of gases. Positive-wave tests made between tungsten rod and 1-in.-diam sphere spaced 1 in. Positive and negative dielectric strength values of No. 10-C oil are shown for comparison

In **Figs. 4, 10, 11,** and **12,** a comparison of the various gases is shown in a uniform field and in the nonuniform field up to 30 lb gage pressure. The insulation strength of oil is indicated by a horizontal line in each graph, because it is little affected by pressure. The comparison is made at 1-in. spacing in the case of the nonuniform field. This provided a high level of breakdown and was not near the 2-in. limit of the cell. In **Figs. 4** and **10,** SF_6 and F-12 appear most hopeful in the comparison of the various gases with oil in a uniform field. However, in the nonuniform-field data in **Figs. 11** and **12,** F-12 suffers decreased strength with increase in pressure, both with 60-cycle and positive-impulse voltages. Sulphur hexafluoride shows an increase in dielectric strength with pressure in **Figs. 4, 10, 11,** and **12** and thereby at 30 lb gage pressure merits careful comparison with oil.

The results of a more detailed comparison between SF_6 and oil in a nonuniform field are shown in **Figs. 13, 14,** and **15.** The tungsten rod was varied in position up to a distance of two inches from the 1-in.-diam grounded sphere and the resulting breakdown values plotted on these graphs. The tests were made at 0, 15, and 30 lb gage pressure of SF_6; finally the same tests were made with the electrodes immersed in oil. The positive-impulse polarity applied to the tungsten rod is the criterion of the lowest impulse strength for SF_6; the polarity effect in the case of oil is negligible. Since either polarity is possible in field applications, the impulse strength of the gas and the liquid should be compared upon the basis of their individual low polarity values as shown in Table I (at 1-in. spacing). Table I is a comparison of data from **Figs. 4, 10, 13, 14,** and **15.**

TABLE I

COMPARISON OF DIELECTRIC STRENGTH OF OIL AND SF_6

	Uniform Field		Nonuniform Field	
	60 Cycles	Impulse	60 Cycles	Impulse
Oil	100 per cent	100 per cent	100 per cent	100 per cent
SF_6 30 lb gage pressure	75 per cent	100 per cent	115 per cent	73 per cent

In actual apparatus, neither the uniform field nor the severe nonuniform field will obtain; these conditions represent the extremes of the problem. Consequently SF_6 will not have the advantage of 115 per cent 60-cycle strength shown in one case, nor the disadvantage of only 73 per cent impulse strength of the nonuniform field used for these tests.

From the foregoing, it appears possible that at a pressure of 30 lb gage, the dielectric strength of SF_6 approaches that of oil. The deficiencies in dielectric strength of SF_6 are small enough that special considerations of spacing and control of dielectric field may place it upon equal footing with oil in some high-voltage apparatus.

In **Figs. 11** and **12**, which concern 60-cycle and positive-impulse breakdown in the nonuniform field, it is noteworthy that some of the halogenated gases show a decrease in dielectric strength with increasing pressure. F-12, F-13, and F-22 do not exhibit a uniform rise in breakdown strength with increasing pressures; in fact, their breakdown strength levels off or decreases.

F-14, F-23, and SF_6 would probably exhibit "anomalous breakdown decrease with pressure" at pressures above the range investigated with the nonuniform field arrangement. This phenomenon has been previously reported for halogenated gases,(5)(6) and also for nitrogen.(2) These investigations have supplied at least a qualitative picture for the departure from Paschen's law; it may be invoked again to explain the present results.

With more complex gases, space charge and its attendant slow diffusion preclude uniform behavior as the pressure is changed. A sharp electrode creates ionization and space charge prior to breakdown, and for example causes the well-known phenomenon of impulse time lag. This prebreakdown space charge sometimes

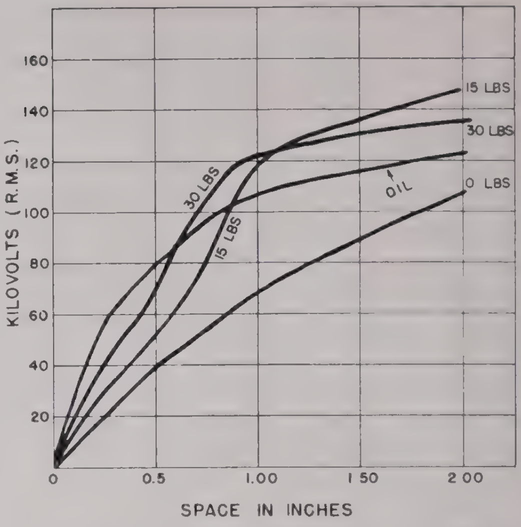


Fig. 13. Sixty-cycle dielectric strength of SF_6 gas. Tests made between tungsten rod and 1-in.-diam sphere (grounded). The dielectric strength of oil is shown for comparison

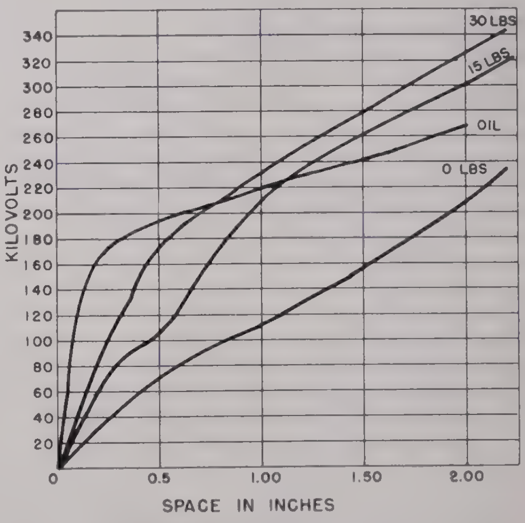


Fig. 14. Negative-impulse dielectric strength of oil and SF_6 gas, with test arrangement as for Fig. 13

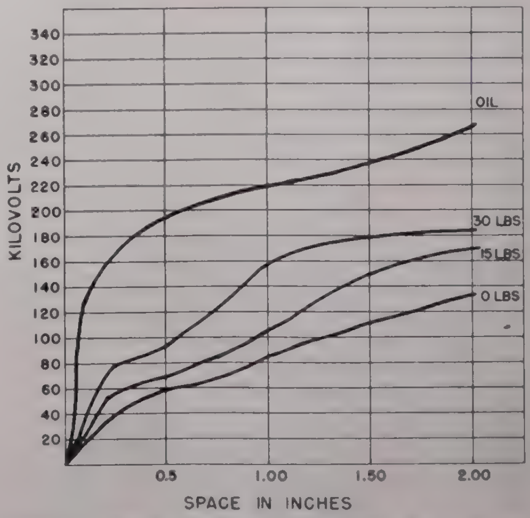


Fig. 15. Positive-impulse dielectric strength of oil and SF_6 gas, with test arrangement as for Fig. 13

---

(5) "Effect of Pressure on Point-to-point Plane Discharge in N_2, O_2, CO_2, SO_2, SF_6, CCl_2, F_2, A, He, and H_2," by H. C. Pollock and F. S. Cooper, *Physical Review*, July 15, 1939, p. 170.

(6) "High-pressure Gas as a Dielectric," by G. C. Nonken, *AIEE Trans.* Vol. 60, 1941, p. 1017.

luces the field gradient in the neighborhood of the arp electrode to such an extent that the final break- wn value is raised considerably.(6)(7) Finally, as the essure is increased further, the breakdown value creases until breakdown begins to occur without any eionization process.(1)

It is thought that streamers from the positive sharp ectrode progress across the gap, creating photon nization which in turn makes the streamers self- opagating. When the pressure is below this critical gion, preionization occurs first, and the breakdown reamer has to break out through a cloud of space arge before it causes failure by propagating itself ross the gap. As the pressure is increased, the diffusion the ions of space charge is decreased, so that streamer opagation may start at the positive electrode before y extensive space-charge cloud is formed.

The streamer formation and propagation process is uite rapid and begins as soon as an ionizing positive tential is applied to the sharp electrode. Electrons e directed toward it; upon acquiring sufficient energy om the electric field, these lead to an avalanche oving toward the positive electrode. A relatively w-moving stream of positive ions are left in the ake, and until they diffuse throughout the volume ey constitute an extension of the positive point. This ament extension propagates itself by causing photon nization in the gas ahead and attracting new aval- nches. With simple gases such as helium and hydrogen, ffusion is much greater, so that such space charge omalies are absent as a function of pressure.

dditional Characteristics of SF_6

Sulphur hexafluoride is a colorless, odorless, tasteless, d noncombustible gas. The solid is a white crystal- e mass; the gas is nontoxic. One of the most attrac- ve features about its prospective application is that it nonflammable and quite inert. It is stable when ex- sed to a silent electrical discharge or when heated to proximately 500 C.

Good stability is shown when this gas is arced at mospheric pressure over a mercury surface in a glass lb. After one hour of continuous arcing, about one r cent of the gas is decomposed. Both the mercury sed for sealing) and the metal electrodes were tacked by the products of decomposition. Examina- on of the solution formed by collecting the gaseous ecomposition products dissolved in water showed the resence of fluoride and sulphite ions.

Dry sulphur hexafluoride has no effect on ordinary etals (copper, steel, silicon steel, and aluminum). ests were made at 110 C with this gas at a pressure of lb per sq in. Examination of the gas at the end of a long ging period showed no evidence of decomposition. The etals had not changed in either appearance or weight.

Aging tests made at 100 C on Kraft paper in the resence of sulphur hexafluoride show that at the end the tests the reduction of the tensile strength is much ss than when paper is aged in the presence of air.

Some physical data on SF_6 are as follows:

Chemical formula	SF_6
Molecular weight	146.06
Gas density relative to air	5.106
Critical temperature	54 C
Weight (lb per cu ft)	0.406 (at 20 C and 760 mm)
Vapor pressure of liquid	See **Fig. 1**
Melting point	−50.8 C
Sublimation point	−63.8 C
Coefficient of thermal expansion of liquid (average −20 C to −50 C) per deg C	0.0029
Refractive index of vapor, n20/D, 760 mm	1.000783
Heat conductivity (unit area)	$=7.1\times10^{-5}$ cal per cm sec deg C (at 25 C)
Coefficient of viscosity	1.61×10^{-4} (at 25 C)
Dielectric constant at 27.5 C	1.00191

Gaseous Insulation Promises Advantages

Compressed gases have been rather slow in finding applications in high-voltage apparatus, especially of the outdoor type. To compete with liquid insulation, such apparatus had to be operated at relatively high pressures to have the dielectric strength of the former. However, the most serious drawback was the liquefaction that occurred at temperatures within the outdoor ambient range.

Sulphur hexafluoride is now available and surmounts these two difficulties. It also merits consideration because of the possibility of improving the design of air-filled apparatus at atmospheric pressure.

Impulse and 60-cycle breakdown tests performed on a group of halogenated compounds in uniform and nonuniform fields indicate that sulphur hexafluoride has superior qualities over the Freons. Thus, this gas increases in dielectric strength with pressure increase until it merits favorable comparison with oil at 30 lb gage pressure.

The more important advantages of gaseous insulation, as maintained by a pressure of SF_6, over liquid and solid insulation may be enumerated as follows:

(1). By using sufficient pressure, the dielectric strength of some gases may rival that of mineral oil. SF_6 accomplishes this at a lower pressure than any other gas explored thus far.

(2). Sulphur hexafluoride and other gases in general are not subject to permanent cumulative breakdown, as is solid insulation.

(3). Sulphur hexafluoride is stable at high temperatures. Most important is the fact that it is nonflammable.

(4). Gases are generally self-healing after breakdown, except where a creepage path over solid insulation is involved. If decomposition of the gas results in a carbon deposit, a permanent type of defect remains. This does not apply to SF_6 because no carbon is contained in its molecular structure.

Acknowledgement

The authors wish to acknowledge the assistance of J. H. Hagenguth and T. R. Walters in the preparation of this article.

---

(7)"The Electric-spark Discharge on Different Gases," by T. E. Allibone d J. M. Meek, *Jour. Sci. Instr.*, Feb. 1944, p. 21.

ELECTRONICS

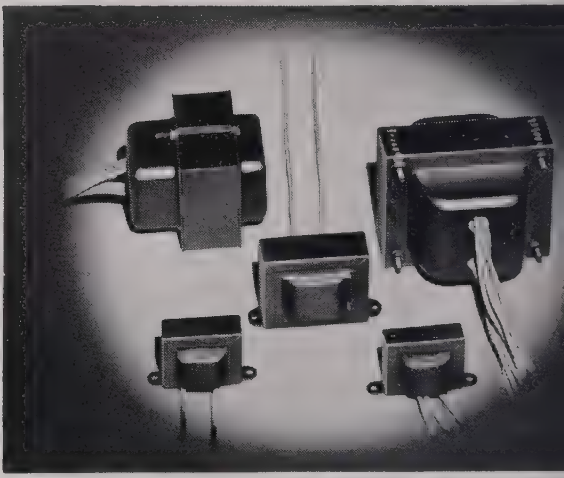
Designer

Television Transformers ... tailored to your needs

1. Line supply voltage and frequency
2. High voltage d-c required
3. D-c milliamperes required
4. Filament volts and amperes
5. Sub-panel or above-panel mounting
6. Description of rectifier circuit
7. Winding insulation voltage required
8. Maximum ambient temperature

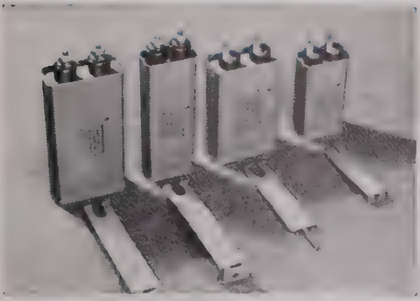
TELL US THESE

WE SHIP THESE



Whatever your transformer needs—power units like these, or special designs for deflection yokes, horizontal or vertical sweeps, or oscillators—General Electric can supply them . . . and quickly. G.E. offers its facilities and engineering "know-how" to television manufacturers in tailoring these transformers to their requirements. Just tell us your specifications and we will meet them to your complete satisfaction. Power-supply transformers are available now in core-and-coil and enclosed-case styles standard units designed for te vision applications. Units for oth uses are tailor-made from standa parts. Ask your G-E representati for more information; you'll pleased with the prices and shi ments he will offer you.

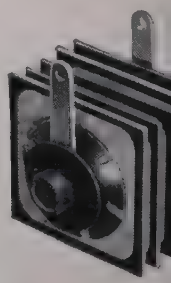
NEW PYRANOL CAPACITORS SAVE SPACE, WEIGHT, MONEY



If you have been using 600-volt d-c capacitors on circuits rated 400 volts or less, you're in for a substantial saving in weight, size and cost by specifying General Electric's new 400-volt Pyranol units. Compared with 600-volt ratings, these new, standard, 400-volt capacitors will save you from 24 to 51 per cent in volume, 23 to 33 per cent in weight, and approximately 10 per cent in cost. They are available in 2-, 4-, 6-, 8- and 10-muf ratings with solder-lug or screw-thread terminals optional on the four larger sizes; the 2-muf size comes with solder-lug terminals only.

New developments, such as silicones and new paper, are continually improving the quality of G-E capacitors. They also permit our engineers to handle your new requirements to your complete satisfaction. Write for quotation on any capacitor needs, or check Bullet GEA-2621 for more informati on the new d-c line describ above.

NEW, SMALLER SELENIUM RECTIFIER



This new General Electric seleniu rectifier, less than one inch lo and one inch square, is availab now for receiver and other ele

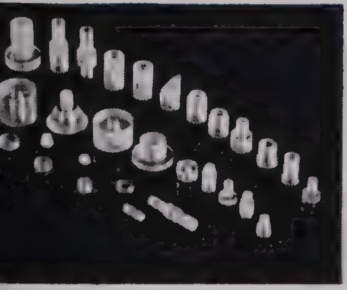
GENERAL ELECTRIC

Digest

TIMELY HIGHLIGHTS ON G-E COMPONENTS

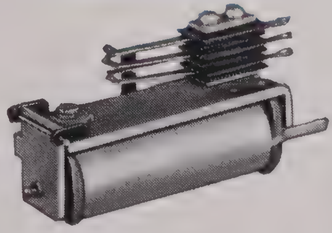
ic applications. It costs little
mounts in places where a rec-
r tube and socket won't fit. Tests
ve that this new selenium rec-
r will outlast several 117-volt
ifier tubes. Installation is easier
—only two soldering opera-
s and a minimum of mounting
lware are required.
hese rectifiers have an excep-
ally high inverse-peak rating,
the inverse current is extremely
even with peak voltages up to
volts. At rated current output,
forward drop is five volts or
. Ratings are based on ambients
0 to 60 C. Check Bulletin 21-
for more information on this
other General Electric radio
ifiers.

NEW MACHINABLE PLASTIC FOR UHF INSULATION



ew arrival in the plastics in-
tor field is G-E No. 1422, which
rs characteristics of advantage
he manufacture of ultra-high-
uency equipment, television,
radar, and radio sets, and many
er electronic applications. Pos-
ing a dielectric constant of 2.5
.6 with a power factor of .0006
0009 at 3000 mc, G-E No. 1422
ibits unusual heat resistance and
ellent machinability.
ndicative of its machinability is
industrial production of r-f connector beads from G-E No. 1422 on automatic and semi-automatic screw machines. As a low-loss dielectric in the hands of the electric-equipment designer, it affords an excellent low-cost means of producing experimental models and small production quantities through the use of standard machine shop tools. Check coupon for technical report.

HANDLES 12 CIRCUITS SIMULTANEOUSLY



This new telephone-type relay is capable of handling as many as 12 circuits in a wide variety of contact combinations. Designed for multipurpose use in industrial electronic apparatus, communications and signaling equipment, these devices have service lives measured in millions of operations. Working from five basic contact arrangements, combinations can be stacked to satisfy intricate circuit switching requirements. Silver, palladium, or tungsten contacts can be supplied; the choice depends on rating and life specifications.

More than 500 different coils are available, with ratings ranging from 1 to 250 volts, and 0.1 to 26,000 ohms. This varied selection of coil ratings makes it possible to match closely the coil voltage and resistance with the rating of the energizing circuits. Check Bulletin GEA-4859 for full details.

TO MEASURE TUBE LIFE

Now available for immediate delivery, General Electric Type KT time meters are ideal for inclusion in transmitters and other electronic equipment where knowledge of tube "on time" is important. They can record operating time in hours, tenths of hours, or minutes, and are built in four forms: round or square for panel mounting, portable with attached base, or for conduit mounting. Those designed for panel mounting are housed in small Textolite cases that harmonize with other panel devices.

Telechron motor drive assures an accurate record of tube operation over a long period of time. They can also be used on electronic production tools, such as resistance welders, to keep an accurate record of machine operating time. Researchers use them for measuring time intervals, verifying circuit operation, and life testing. Bulletins GEA-3299 and GEA-1574 have full details.

GENERAL ELECTRIC COMPANY, Section E642-16
Apparatus Department, Schenectady 5, N. Y.

Please send me:

☐ GEA-2621	400-v D-c Capacitors	☐	21-127 Selenium Rectifier
☐ GEA-3299 ☐ GEA-1574	Type KT Time Meter	☐ ☐	GEA-4859 Telephone-type Relay Report on G-E No. 1422 Plastic

NOTE: More data available in Sweets' File for Product Designers.

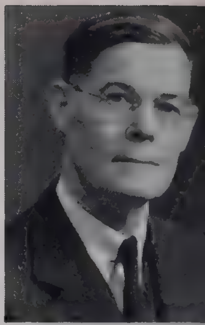
Name..

Company..

Address..

City..State..................

INDUCTION HEATING APPLICATIONS



N. R. Sta

At all temperatures, flux distribution, eddy currents, and electrical efficiency are related through mathematical formulas. How they apply to temperatures below melting point

By N. R. STANSEL
Schenectady, New York

INDUCTION heating in industry can be divided into three groups: heating conductive materials (mainly metals and alloys) to temperatures below their melting points; the melting of metals and alloys; and miscellaneous applications. The scope of this article will be confined to the first mentioned.

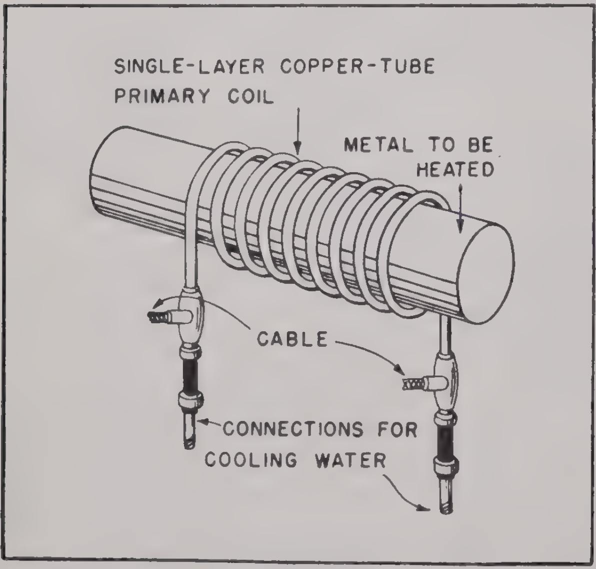

SINGLE-LAYER COPPER-TUBE PRIMARY COIL
METAL TO BE HEATED
CABLE
CONNECTIONS FOR COOLING WATER

Fig. 1. An assembly for induction heating

Applications

Heat applications are classified as mass heating and surface heating. In mass heating, such as heating for forging and heating for annealing, the object is to obtain a uniform temperature throughout the mass of the charge. The term "through heating" is also in current use. Surface heating or zonal heating requires the heat effect only in the near-surface zone of the charge. The principal use of surface heating is heating steel for surface hardening.

The charges which can be heated include all conductive materials, and there are many shapes and sizes. There is a plurality of objectives and a wide range of specified temperatures.

Two features which distinguish induction heating
the internal development of heat, which makes r
heating practicable and economical, and heat placem
in which the development of heat is confined to the
of the charge which is exposed to the magnetic flu

Similarly, there are conditions of operation which
peculiar to induction heat-treating. A one-piece ch
is used. The division of the charge into lengths, a
heating billets for forging, does not change this desi
tion. Furthermore, there is the absence of a heat re
voir (refractory) around the charge and likewise
absence of heat insulation around the charge.

Assemblies. The requirement for induction hea
is the exposure of the lateral surface of the charge t
alternating (or varying) magnetic flux, the direct
of which are parallel to that surface of the charge.
arrangement of parts for that exposure is termed
assembly. There are a number of these assemblies in
The most common are:

(1). A coil around the charge, as shown in **Fig.**
(2). A coil in the bore of a hollow charge.
(3). The charge is adjacent to the side or to one
of a coil.

Shape of Charge. Any shape of charge can be hea
Shape alone does not affect the principle involve
only introduces the complication of its geometry.

Cardinal Relations

The factors which determine the distributio
alternating magnetic flux and of the resultant
currents in the mass of a charge are the electric
magnetic properties of the material, the frequency,

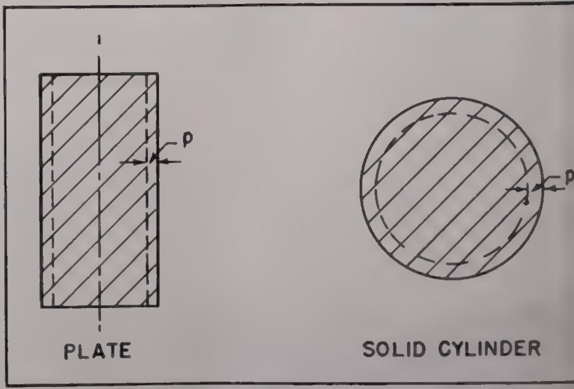


Fig. 2. Reference dimension diagram

Prior to his retirement in 1946, Mr. Stansel was for years a member of Industrial Engineering Divisions of the Apparatus Department, General Electric Company.—ED.

This article will constitute part of the book *Induction Heating* by N. R. Stansel to be published by McGraw-Hill Book Company (New York). It is preprinted here by permission of the author and publisher.—ED.

This article is so paged that, without mutilating other articles, it can be conveniently removed for separate filing by tearing out pages 44 to 50.—ED.

dimension of the charge that is normal to ateral surface. This dimension is termed base dimension and for the two most mon shapes of charges is: the radius, for lid cylindrical charge; one-half the thick-, for a rectangular charge.

he relations of these factors are expressed he three equations which follow:

eference Dimension. This dimension is a tion of the base dimension measured n the lateral surface of the charge, as cated in **Fig. 2**, in which

$$p=\frac{\sqrt{\rho_a 10^9}}{2\pi\sqrt{2}\sqrt{\mu f}}=3560\frac{\sqrt{\rho_a}}{\sqrt{\mu f}}\text{ cm} \qquad (1)$$

here

ρ_a = the resistivity of the material of the charge, ohm-cm^3

μ = the permeability of the material of the charge

f = the frequency in cycles per second

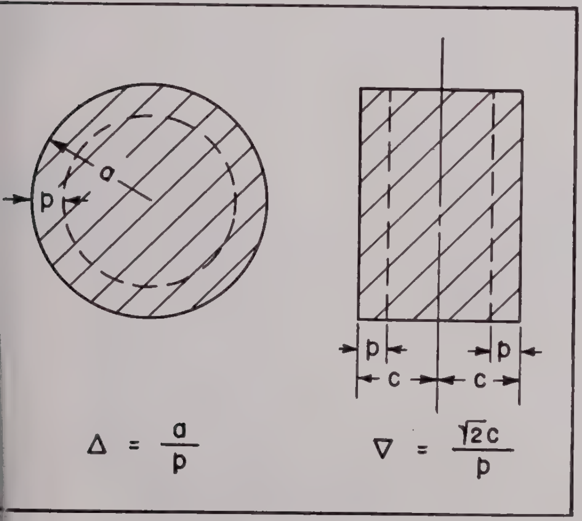


Fig. 3. Index ratio diagram

ex Ratio. This term denotes the ratio of the base nsion and the reference dimension—thus, for solid drical charge (**Fig. 3**), the index ratio

$$\Delta=\frac{a}{p} \qquad (2)$$

or a charge with rectangular section, the index

$$\nabla=\frac{\sqrt{2}\,c}{p} \qquad (3)$$

d Index Ratio. This is the value of the index ratio corresponds to the values of the resistivity and rmeability of the charge when it is at the tem- re specified for the heat application. This ratio basis of the design of induction-heating appara-

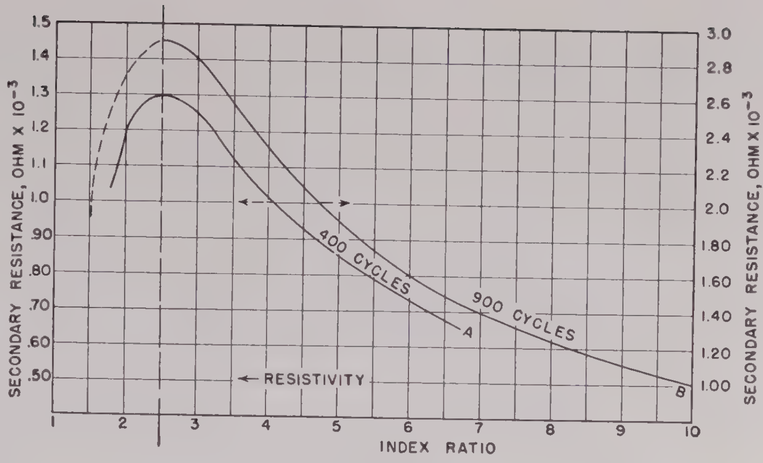


Fig. 4. Effect of charge resistivity on secondary resistance

Electrical Efficiency. The efficiency of the transformation from electric energy to heat is

$$\eta=\frac{r_a}{r_b+r_a} \qquad (4)$$

where

r_a = the resistance of the path of the current in the charge—the secondary circuit—in ohms

r_b = the resistance of the corresponding primary circuit—the coil around the charge—in ohms

The importance of this efficiency relates mainly to the effectiveness of the heating operation.

Resistance-Index-Ratio Relation. The curve in **Fig. 4** shows the relation between the resistance of the secondary circuit in a solid cylindrical charge and its index ratio, on the basis of unit permeability and rising temperature—that is, increasing resistivity. The peculiar feature of this relation is the inversion point which occurs with the index ratio 2.50.

Power. The primary power in an assembly is

$$P_b=\frac{e^2R}{Z^2}\text{ watts} \qquad (5)$$

and in the charge

$$P_a=\frac{e^2r_a}{Z^2}\text{ watts} \qquad (6)$$

where

e = applied voltage in volts
R = the effective resistance (r_b+r_a) in ohms
Z = the corresponding effective impedance in ohms

With constant current, the variation of power with rising charge temperature would be shown by a curve having the shape of that in **Fig. 4**—that is, the maximum power with the index ratio 2.50.

The effective impedance increases with rising temperature of the charge. Hence, with constant applied voltage e, the curve showing the relation between power and the index ratio with rising charge temperature may or may not exhibit a maximum power value. That, for a given assembly and a given range of temperature, depends on the frequency, as shown in **Fig. 5**.

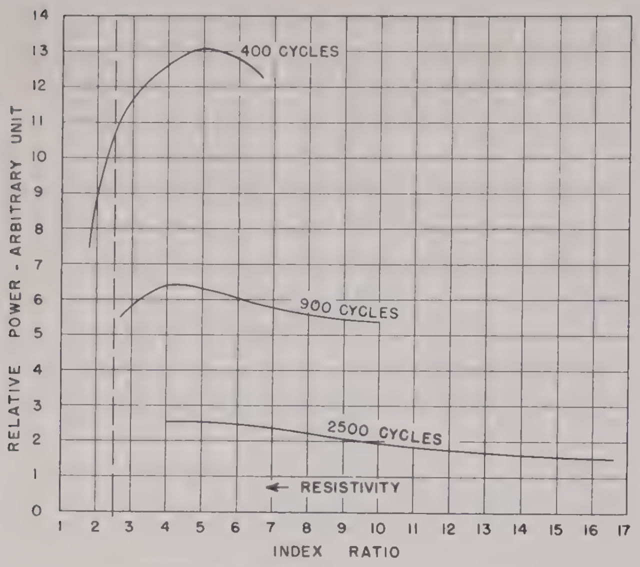


Fig. 5. Effect of charge resistivity on power (rate of heat development in charge) with constant voltage at different frequencies

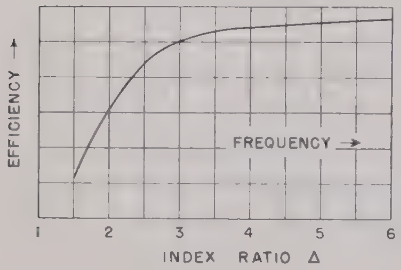


Fig. 6. Effect of frequency on electrical efficiency with a solid cylindrical charge

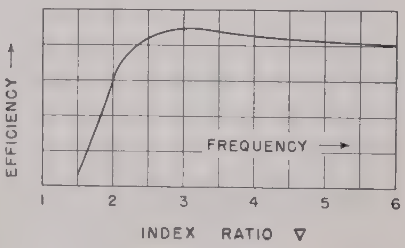


Fig. 7. Effect of frequency on electrical efficiency with a rectangular charge

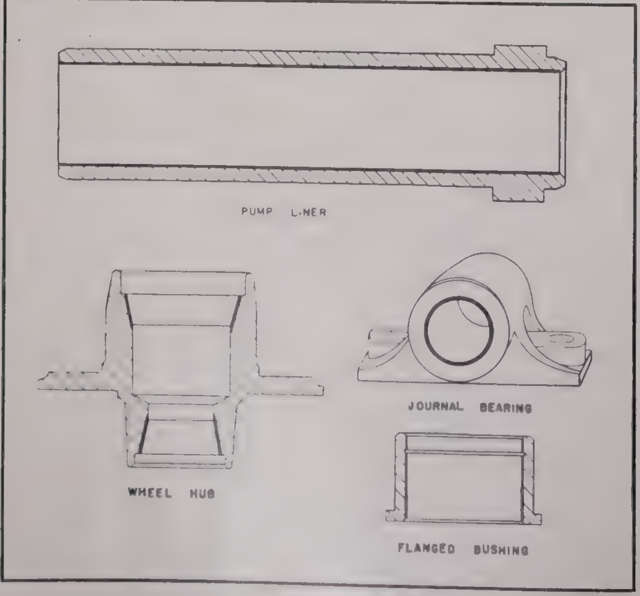


Fig. 8. Types of internal surface-hardened parts

TABLE I
SOLID, CYLINDRICAL, ALUMINUM CHARGES A FORGING TEMPERATURE

Diameters		Frequencies		
Inches	Centimeters	9600	3000	960
		Rated Index Ratios		
0.25	0.635	2.60	1.47	0.8
0.50	1.27	5.25	3.0	1.6
0.75	1.90	7.86	4.4	2.4
1.0	2.54	10.5	5.9	3.3
1.5	3.81	15.7	8.8	5.0
2.0	5.08	20	11.7	6.6

The curves in **Figs. 4** and **5** illustrate a basic p
ciple of the eddy-current phenomenon which is app
able to any shape of charge. This principle is sta
thus: an increase of charge resistivity is favorabl
the development of heat if that increase does not
crease the index ratio below the inversion-point va
an increase of charge resistivity is unfavorable to h
development if the result of that increase is an in
ratio less than the inversion-point value.

It will be observed that the first condition pert
to the use of eddy currents for heating service, whe
the second condition relates to the minimization of
eddy-current loss in electrical apparatus.

In the design of electrical apparatus, the needed
value of the index ratio is obtained according to
conditions by a correlation of a small base dimen
and the resistivity of the material of the part. In ind
tion heating, the only factor of choice to obtain
needed comparatively high value of the index rati
frequency.

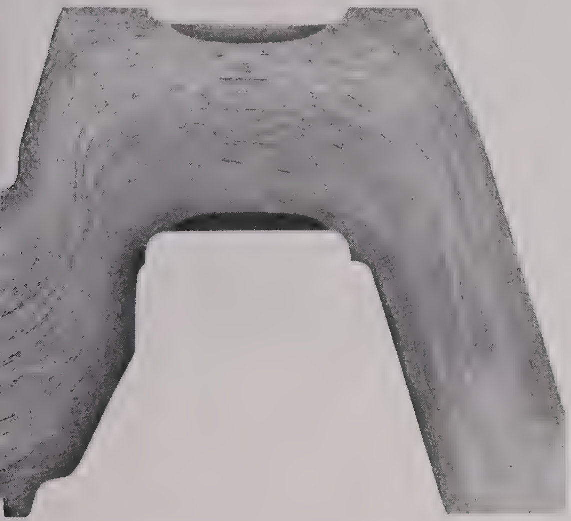
These considerations introduce the concept of *t*
and thin bodies, referring respectively to high and
values of the index ratio. This concept is also us
with reference to the flow of heat within the mass
charge.

TABLE II
SOLID, CYLINDRICAL, STEEL CHARGES AT FORGING TEMPERATURE

Diameters		Frequencies		
Inches	Centimeters	9600	3000	960
		Rated Index Ratios		
0.50	1.27	1.58	0.88	0.5
0.75	1.90	2.38	1.32	0.7
1.0	2.54	3.18	1.76	1.0
1.5	3.81	4.76	2.64	1.4
2.0	5.08	6.35	3.52	1.9
2.5	6.35	7.93	4.40	2.
3.0	7.62	9.52	5.40	2.9

fficiency-frequency Relation. The curve in **Fig. 6** illuses the effect of frequency on the electrical efficiency n assembly with a solid cylindrical charge. There is e gain in this efficiency by increasing the frequency ond the value which gives the index ratio 5 or 6.

n the case of an assembly with a rectangular charge, frequency which gives the index ratio value about



. 9. Longitudinal section of a surface-hardened crank-pin bearing journal

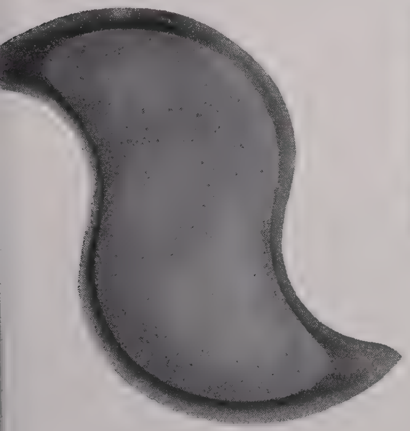


Fig. 10. Steel brake-cam, surface-hardened

is the optimum frequency with respect to the efficy, as shown in **Fig. 7**. This optimum value is of or importance.

s Heating

tion of Frequency

he frequencies in general use for induction heating— therefore termed standard frequencies here—are 3000, and 9600 cycles, and around 450 kilocycles. ne technical criterion for the selection of frequency given charge is electrical efficiency. The economic ideration is the use of a standard frequency. As a both the technical and economic requirements are as follows:

lid Cylindrical Charge. A standard frequency which a rated index ratio within the range 2.50 to 6.0. upper values are preferred.

Charge with Rectangular Section. A standard frequency which gives a rated index ratio within the range 1.70 to 5.0. An intermediate value is preferred.

Miscellaneous Shapes. There are many charges other than those with cylindrical and with rectangular sections. The object in such cases of irregular shapes is to obtain a frequency which is effective for heating the bulk of the charge but which is ineffective for the development of eddy currents in edges and projections. This leaves the latter portions of such charges to be heated by thermal conduction.

Example 1. Selection of frequency for heating a solid cylindrical charge of steel to forging temperature.
Charge radius $a=1$ in. (2.54 cm)
Resistivity $\rho_a=125/10^6$ ohm-cm^3
Assumed rated index ratio $\Delta=6.0$
Reference dimension $p=0.423$ cm, Equation (2)
Frequency, $f=8855$ cycles, Equation (1)
Nearest standard frequency 9600 cycles

Standard Frequencies. Examples of the adaptability of standard machine frequencies to charge dimensions are given in Tables I and II. For example, a ¾-in.-diam solid aluminum charge is within the range of the three standard frequencies.

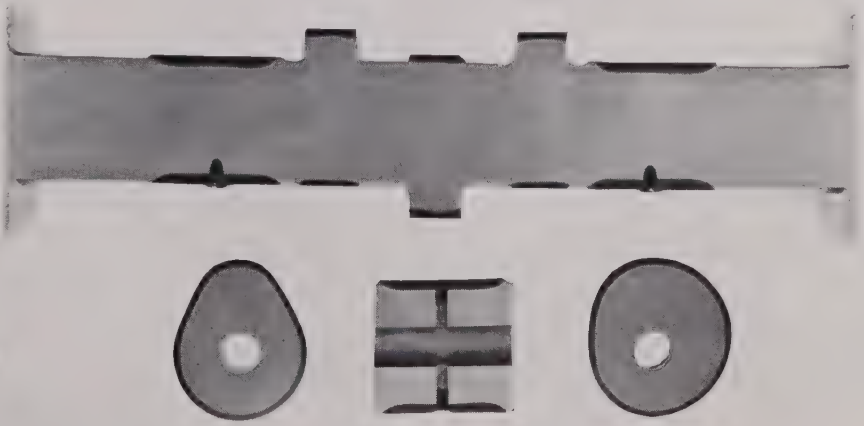


Fig. 11. Cam shaft with surface-hardened bearing surfaces

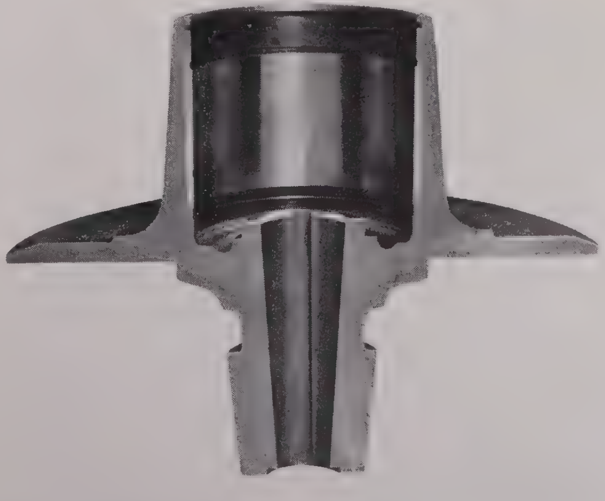


Fig. 12. Section of cast-iron wheel hub with surface-hardened bearing race

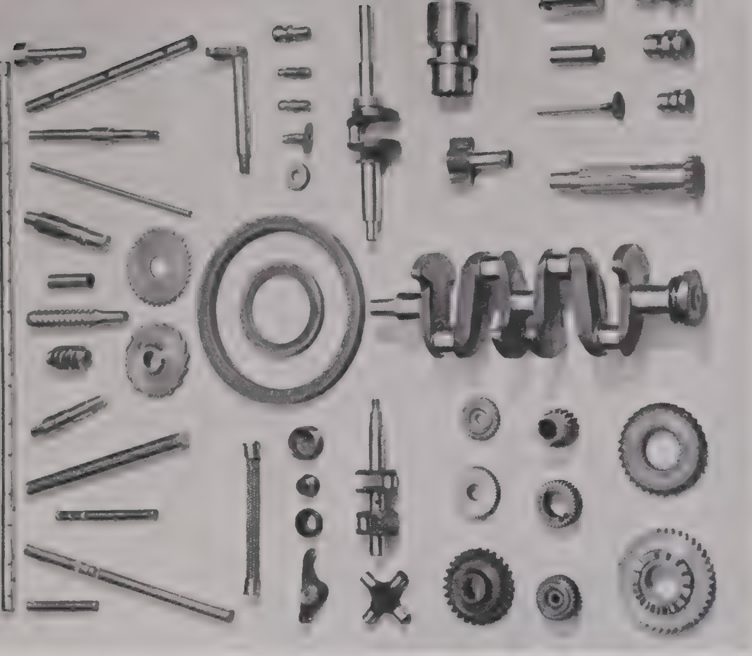
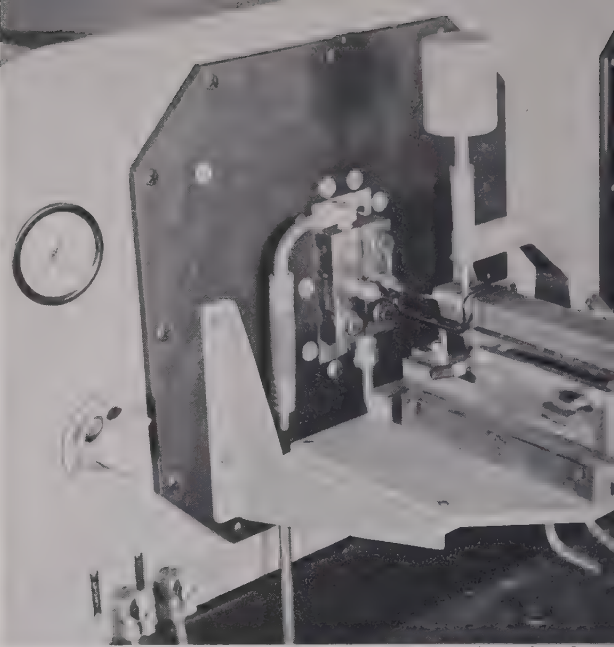


Fig. 13. Typical machine parts, surface-hardened



(The Ohio Crankshaft Comp

Fig. 14. Front view of an induction heater for brazing cutting tips on t

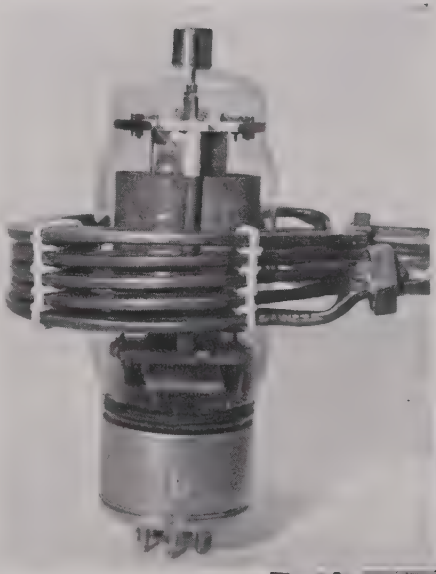


Fig. 15. An assembly for degassing an electron tube

(Radio Corporation of America)

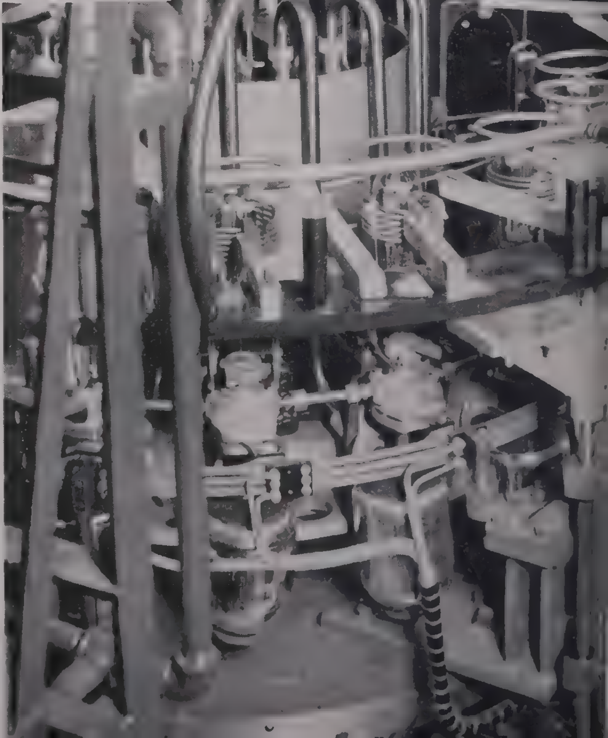


Fig. 16. An autom electron-tube evacua machine

In the case of a magnetic material to be heated to a temperature above the Curie point, the initial boosting effect of the magnetic property on the rate of heat development can be considered in the selection of frequency. For example, referring to Table II, 9600 cycles is effective for steel charges down to a diameter of about one half inch.

Plant Economies

There may be, and often is, a variety in the heating service of a plant, such as: charges of different materials; a range of diameters (or thicknesses) of charges of a given material; different heat applications; and some combination of these conditions.

A single standard frequency which is effective for the entire range of work in the plant is desirable. In some cases a preponderance of one service may justify a frequency selected for that service alone.

Surface Heating

It can be shown that, with rated index ratios above 4.0, approximately 76 per cent of the heat development in a charge occurs in the annular zone which has a radial thickness equal to the value of the reference dimension p [Equation (1)]. This is referred to here as heat concentration. Inasmuch as the reference dimension is inversely proportional to the square root of the frequency, this concentration of heat in the annular zone of the charge can be made as desired by the selection of frequency.

rface Hardening

This heat-treatment process is defined as hardening outer layer of a steel part without affecting the ystal structure of its core.

Three features of induction heating make that ethod particularly well suited for surface hardening. iese are: the heat concentration; the more or less rupt decrease of the rate of heat development with e transformation of the outer layer of the charge to e nonmagnetic state; and the axial localization of the at development.

Each application of heat for hardening steel is a part a metallurgical operation with reference to a particu- steel for a particular service. Frequently, experi- ental studies are made to determine the technique the operation. With respect to the heating phase of is heat-treatment process, good practice for mass ating is likewise good practice for surface heating. In me cases, a frequency higher than would be used nerally for mass heating is used to obtain a very thin rdened layer.

Figs. 8 to **13** inclusive show representative examples the use of induction heating for surface hardening.

stallations

Brazing. The front view of an induction heater for azing cutting tips on tools is shown in **Fig. 14**.

Degassing Tubes. In the evacuation of an electron be it is necessary to include the removal of gases and pors occluded in the metal parts within the glass velope. This is accomplished by heating these parts eddy currents, during the evacuation operation.

An assembly for this evacuation service is shown in **g. 15**. An automatic evacuation machine for quan- y production of tubes is shown in **Fig. 16**. Note the semblies which correspond to **Fig. 15**.

Induction Heaters. A typical induction heater for the ntinuous heating of billets is shown in **Fig. 17**.

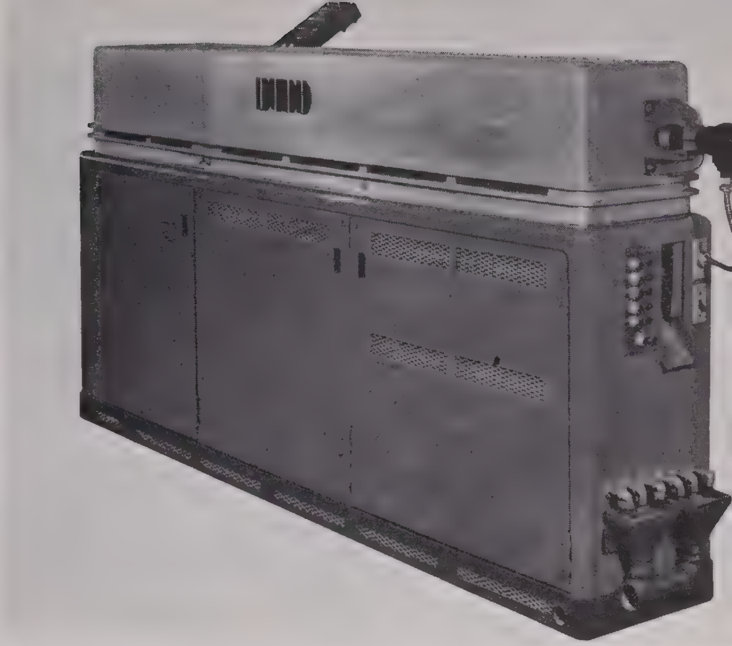
Heating Aluminum. The installation in **Fig. 18** for up- tting aluminum propeller hubs contains five induc- n heaters, each rated 50 kw, 3000 cycles, 350 volts. ie handling mechanism for the charge is of the car- ge type. The upsetting machine is in the left back- ound. The output of the five heaters in normal produc- n is one propeller blade ready for upsetting every 47 conds, a production of 70 blades per hour.

Heating Steel. An installation for the production of el forgings is shown in **Fig. 19**. This installation con- ns eight units, each with seven induction heaters, d an upsetting machine.

Each heater is rated 100 kw, 960 cycles, 400 volts. ie over-all efficiency is 4.8 lb of steel per kw-hr.

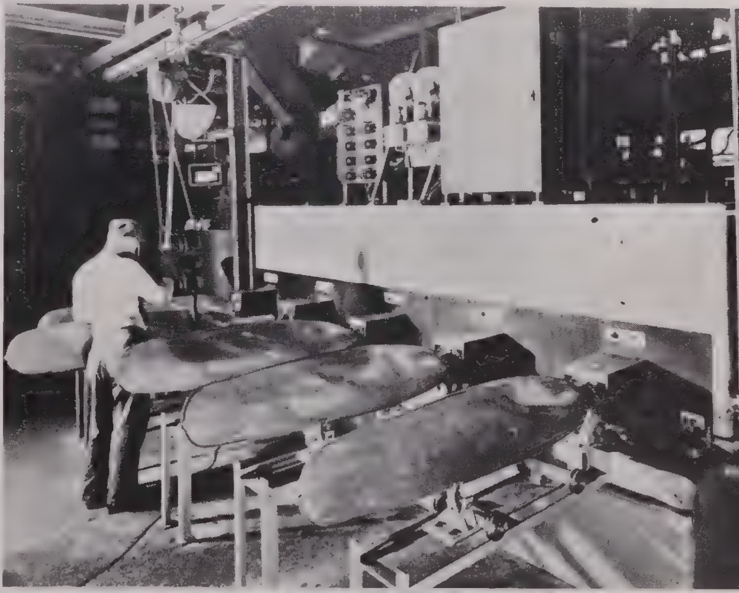
Heating Steel for Hardening and Tempering. The machine own in **Fig. 20** comprises two induction heaters, a enching device, and a conveyor for continuous rough hardening, followed by tempering, of solid und bar stock with diameters of one-half to three hes, random lengths. A protective gas atmosphere used.

(Concluded on p. 50)



(The Budd Company)

Fig. 17. An induction heater for continuous heating of billets for forging

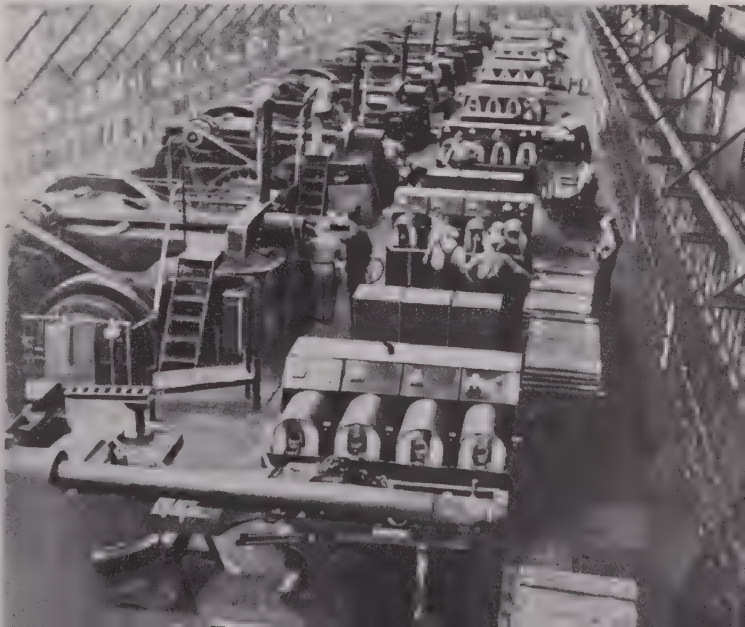


(The Ohio Crankshaft Company)

Fig. 18. An installation for forging aluminum propeller-blade hubs

Fig. 19. An installation for the production of steel forgings

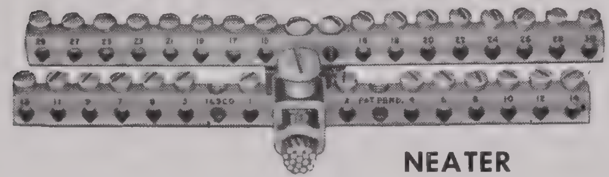
(Ajax Electrothermic Corporation)



At Last THE GREATEST INNOVATION IN ELECTRICAL CONNECTIONS

ILSCO
NEUTRAL BARS

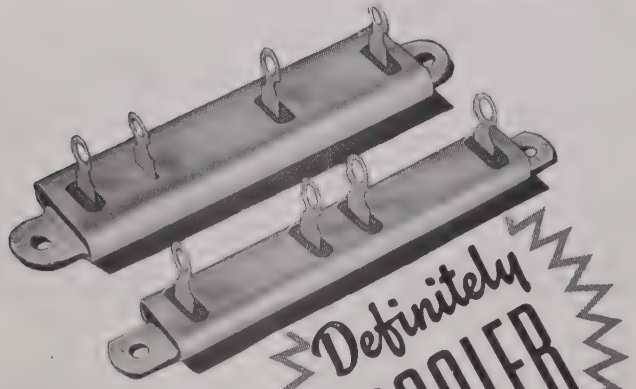
70, 125 and 225 ampere



NEATER
MORE COMPACT
BETTER CONNECTIONS
ECONOMICAL
APPROVED

Write today for details and 48-page illustrated catalog.

ILSCO COPPER TUBE & PRODUCTS, Inc.
CINCINNATI, OHIO



Definitely COOLER

Resistance values from fraction of an ohm to 15,000 ohms per winding inch. 2½ watts per winding inch in free air; 5 watts when mounted flush on metal radiating surface.

★ Clarostat Series MMR bakelite-insulated metal-clad resistors are definitely COOLER than any other similar types, SIZE FOR SIZE; or putting it another way, these resistors will DISSIPATE MORE POWER for the same temperature rise, SIZE FOR SIZE.

☆ ☆

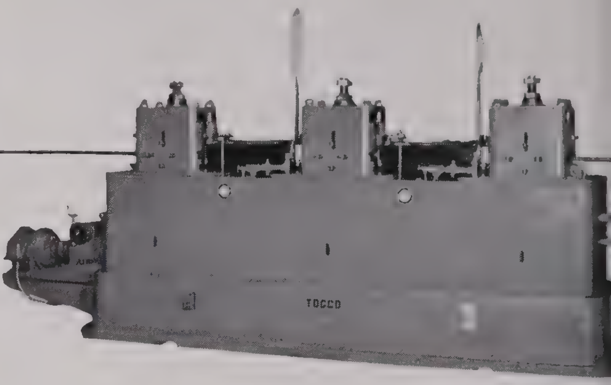
That's our statement. We invite your own tests. Sample on request if you write on your business letterhead. Also detailed literature.

CLAROSTAT Controls and Resistors
CLAROSTAT MFG. CO., Inc. · 285-7 N. 6th St., Brooklyn, N. Y.

INDUCTION HEATING APPLICATIONS

(Continued from preceding pa

The arrangement of the primary coils, or inducto and the general design of these coils are shown in F 21. The handling mechanism is an adjustable-spe motor-driven roller conveyor.



(The Ohio Crankshaft C

Fig. 20. An induction heating machine for continuous heat treatm steel-bar stock

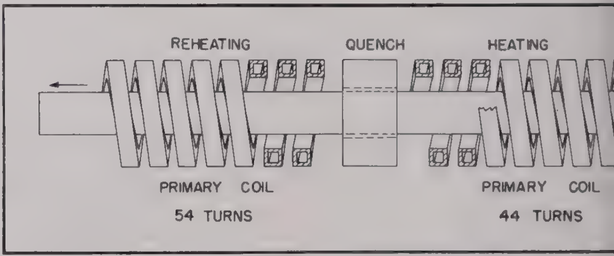


Fig. 21. General design and arrangement of the primary coils, inductors, of the machine shown in Fig. 20

This application is a heat-treatment process, and t quality of the product takes precedent over speed. normal performance of this machine is 250 lb of S 1045 steel hardened to 63–64 Rockwell C and temper to 30–31 Rockwell C per hour. One operator is su cient for eight machines in a group. Such an instal tion would produce 2000 lb of heat-treated steel hour.

SEXTON CAN COMPANY
Incorporated
Everett Massachusetts
Manufacturers of
Ash Barrels Underground Garbage Receivers
Kitchen Waste Cans
CAPACITOR CASES
both Fabricated and Deep Drawn
FIVE GALLON
Open and Closed Top Shipping Containers
METAL STAMPINGS
SPECIAL SHEET METAL WORK

HERE'S GOOD NEWS, Mr. Manufacturer!

PHILLIPS CONTROL CORPORATION *Announces* REDUCED PRICES ON ELECTRICAL AND ELECTRONIC COMPONENT PARTS

—A CONTRIBUTION TO NATIONAL CRUSADE AGAINST INFLATION

Every straight-thinking American knows that prices cannot continue to climb without reaching a danger point where our national economy may be seriously threatened. Combatting inflation, then, is a primary duty of every responsible citizen and company. We must all contribute, within our means, to any action leading to lower prices.

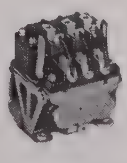
We at Phillips are happy to announce that, effective immediately, prices on most electrical and electronic component parts are cut from 5 to 15 per cent.

During the past year, because of our improved facilities, more efficient production methods, and the splendid cooperation of every Phillips employee it has been possible to step up our production substantially. Production cost per unit has been lowered. Our sales for 1947 were double those of 1946, and judging from the backlog of orders on hand plus the accelerated demand for Phil-trol products, 1948 sales will again reach a new high.

In a letter written by Mr. C. E. Wilson, President of General Electric Company, in announcing price reductions on G. E. products, he said "We expect to maintain these prices provided no further increase occurs in our own labor costs or in prices of components and materials which we purchase in so great a measure from others. . . ."

By lowering prices on Phil-trol component parts, we hope to be of modest aid to companies like General Electric and the many leading manufacturers that we supply. Although but one link in a large chain, our action should help our customers to hold down their costs which ultimately will bring about lower prices to the consumer public—which means all of us.

We invite all manufacturers, large and small to make announcements similar to this one. Remember! G. E. and others who have taken this lead cannot in themselves alone make this crusade a successful one. *Every* supplier and manufacturer as well as every worker must cooperate. After all it's for the benefit of we the people, the factory worker, the office worker, the executive, the housewife and every American—*so why not do it?* Let's do this job—let's bring prices DOWN.



Phil-trol PRODUCTS

Relays, Actuators, Solenoids, Contactors, Starting Switches, Focus Coils, Ion Traps and Special Process Control Assemblies

PHILLIPS CONTROL CORPORATION • 612 NORTH MICHIGAN AVENUE • CHICAGO 11, ILLINOIS
PLANT: JOLIET, ILLINOIS • SALES OFFICES: NEW YORK, BOSTON, PHILADELPHIA, BUFFALO, CLEVELAND, CHARLOTTE, ST. LOUIS, KANSAS CITY, LOS ANGELES, TORONTO

HIGH LIGHTS and SIDE LIGHTS

Electronic Newspaper

"Electronic newspaper" equipment, recently built for the *Miami Herald*, transmits words and pictures through the air on FM radio waves and prints these items on paper coming from receivers which may be installed in the home, office, or other place of business.

The new equipment will be used for facsimile programming experiments. For the initial experiments, plans are being made to broadcast stock-market reports, news, and other items of importance, including pictures, to business firms and executives.

Tests by newspaper and radio stations using this equipment should indicate what the public wants in the way of facsimile receivers. It is expected that this experience, plus market studies, will provide information as to the type of facsimile receivers required, styling details, price brackets, and other essential information.

Words and pictures are sent out on FM radio waves from this transmitter console and recorded on paper in home or office.

Floating Radar Lab

Three types of radar and a new ante have been installed on the S.S. *Fraser* of the Pittsburgh Steamship C pany for a commercial-shipping r research program on the Great Lakes.

The equipment is being tested unde conditions in an effort to determine most useful type of radar equipment boats on the Lakes. The *Leon F* operates from Conneaut (Ohio) to Du (Minn.) and other Great Lakes ports.

Including installation of existing t of commercial marine radar with features along with recently desi units, the research program has made boat a "floating radar laborato

Since October 1 the following typ radar equipment have been underg tests: (1) The standard "S-band" E tronic Navigator, which has been use the Great Lakes for the past two y Equipment aboard the *Leon Fraser* util improvements in antenna design electrical circuits. It functions a frequency of 3200 megacycles. (2 second type of radar, called "X-ba which operates at a frequency of megacycles. Employing a specially signed antenna to furnish a "ne sharp" radar beam, it proved to be of g value in plying the narrow channels breakwaters on the Great Lakes. ("Master Navigator" or ten-inch pic tube unit which can be connecte either type of radar and located anyw aboard the boat.

Detecting Gases Electronically

A "robot chemist," which uses electronics to determine the chemical content of gases and vapors quickly and accurately, and which automatically records its findings, has been developed for industrial and research applications.

Known to scientists and engineers as the "analytical mass spectrometer," the instrument is so sensitive that it can detect traces of one gas so minute that they represent only one part of 100,000 parts of another gas.

Formerly confined to laboratory research work, the mass spectrometer is seen as of especial value to the chemical and allied industries. For hydrocarbon analysis of synthetic rubber, gasoline, and other petroleum products, the analytical mass spectrometer requires but one tenth the time needed by ordinary methods of chemical analysis.

The time needed for analysis and calculation of the chemical composition of a sample depends upon the number of its components, the complexity of the mixture, and the interference of one component with another. The instrument can be operated by a person without technical training after the method of analysis has been determined by a technically trained supervisor.

The compound to be analyzed is introduced into an ionization chamber, where its molecular particles are given electric charges. The molecules then are accelerated through a magnetic field, which causes them to follow a curved, rather than straight, path. Because heavier molecules are deflected to a lesser degree than the lighter ones, the particles are spread across a collector plate in a molecular spectrum according to their weights, from 1 to 350, permitting an accurate analysis of the sample's constituents.

FM Traveling Workshop

A total attendance of 10,607 was reported for the traveling FM radio workshop for its three-month tour of 24 states and the District of Columbia.

Although radio servicemen made up the majority of the audiences, broadcast engineers, educational instructors, and veterans studying electronics at government-sponsored schools contributed heavily to the groups at many cities.

One of the most interesting meetings was held at Omaha (Neb.), where the audience included 75 blind or partially blind men who were studying the servicing of radio receivers. These men build their own equipment, with raised dials and meters.

A notable feature of the tour was the interest shown by the radio servicemen in visual alignment of receivers.

The meetings of the FM traveling workshop dealt with alignment procedures in regard to FM receivers and various FM circuits.

Two of the blind students attending the R Engineering Institute at Omaha (Neb.) ins equipment of the FM Traveling Workshop du one of its conferences for radio servicemen

MALLORY ORIGINATED ELKONITE* METALS–

ELKONITE

and only Mallory has the years of experience with their complex fabrication

ELKONITE is the registered trade mark for a series of metals originated by Mallory which derive their effectiveness from the skillful compounding that Mallory has developed through many, many years of pioneering in the field of powder metallurgy.

Elkonite metal proved so dependable under the most severe conditions that it quickly became standard on most heavy duty circuit interrupting equipment. It also proved indispensable in the field of resistance welding and in countless applications requiring its particular characteristics.

The success of Elkonite metal is so well established that the trade mark has been mistakenly applied to materials that are sold with the implication that they will match the performance of true Elkonite metal.

Mallory has made true Elkonite metals for years. Only Mallory can guarantee the correct formulation that gives hardness, high electrical conductivity, resistance to mechanical wear and to sticking and erosion by arcing—the qualities that have made the word Elkonite a symbol of dependability.

ONLY MALLORY MAKES AND SELLS GENUINE ELKONITE METAL

**Reg. U. S. Pat. Off.*

P. R. MALLORY & CO. Inc.
MALLORY ELECTRICAL
CONTACTS & CONTACT ASSEMBLIES

P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

NEW PRODUCTS: AND WHAT THEIR MAKERS HAVE TO SAY ABOUT THEM

Oil-bath Pots

Pint and two-quart electrically heated oil-bath pots for laboratory use. The pots are sturdily constructed of cast aluminum housing with inner pots of spun steel. Insulated resistance wire in numerous circuits is cemented uniformly over the sidewalls and bottom on the outside of the inner pot. Thus, uniform coverage is obtained, providing an even heat at low concentration. This type of wiring allows for a low-wattage heating unit which operates at black heat to provide long life. These pots are furnished with a specified wattage. However, similar pots with either fixed or variable thermostat control are available.—*Sta-Warm Electric Co., Ravenna, Ohio.*

Magnetic Coupling

Use of two sintered alnico permanent magnets separated by an aluminum diaphragm provide a leak-proof type of magnetic coupling for an improved liquid-level gage made by the Boston Auto Gage Co. for use in transformers. The gage accurately indicates the level of the insulating liquid in the transformer. A float inside the transformer tank transmits the motion of the liquid to one of the magnets, which in turn transfers its motion by a powerful magnetic flux to a similar magnet placed on the other side of the diaphragm and attached to a dial indicator needle. The diaphragm is pressure-tight to a minimum of 30 lb per sq in., effecting a permanent seal between liquid and gage proper. To seal the opening where the gage is installed, the flange is mounted with four studs to the side of the tank, usually below the maximum oil level, and then sealed by a gasket. —*General Electric Co., Chemical Dept., Pittsfield, Mass.*

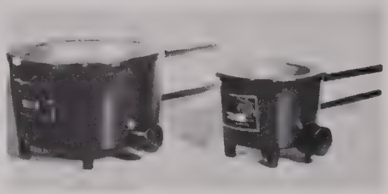
Filters

A new series of Elim-O-Stat heavy-duty radio-interference filters, Type EB, for wiring circuits, screen rooms, and industrial electrical equipment. These filters are furnished in standard Underwriters' approved heavy cadmium-plated steel-surface cabinets. Individual filter units in each assembly are housed in hermetically sealed corrosion-resistant metal containers. Their noise-elimination range of 150 kc to 250 mc covers all frequencies used for radio communication and entertainment, as well as commercial television.—*Solar Manufacturing Corp., 1445 Hudson Blvd., N. Bergen, N. J.*

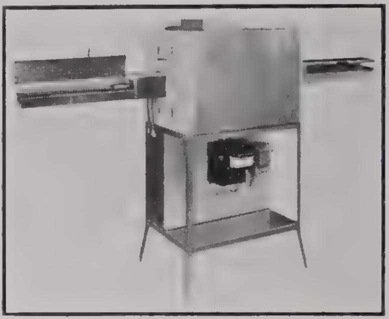
Moisture Tester

The use of a new instrument called the electric Hygro-Cel eliminates defective castings and the destruction of sand molds due to improper moisture conditions within the mold during pouring. The evaporation of moisture can be accurately measured by placing the instrument in contact with the surface of the mold. Tests show that the best time to pour sand-cement molds is when the evaporation from the surface of the mold drops to approximately zero.

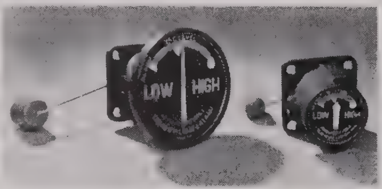
The operating principle of the instrument is based on the ability of a hygroscopic film to change its electrical resistance instantly with microscopic changes in moisture content. The instrument can be used in small spaces, since no dimension of the housing exceeds three inches.—*The American Instrument Co., Silver Spring, Md.*



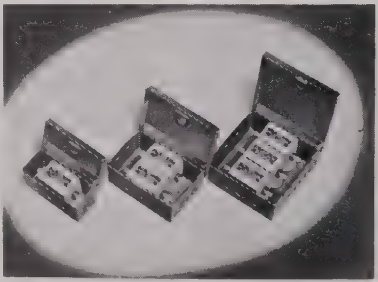
Oil-bath Pots



Tunnel Kiln

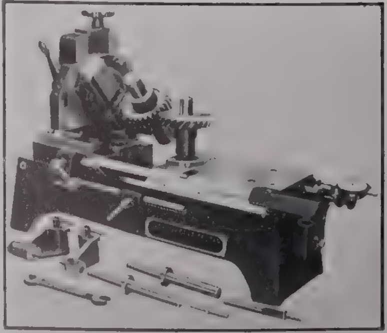


Magnetic Coupling



Filters

Cable Clamps



Gear Tester

Tunnel Kiln

A new pusher-type tunnel kiln,
signed for small-batch production wo
firing of ceramic parts, and heat treating
small parts on a production basis featu
an electric-heating element that provide
maximum temperature of 2200 F. Sm
refractory trays are pushed through
inside of the 33-in. firing chamber by mea
of a variable-speed drive. The kiln is c
structed of No. 14 gage steel, and the s
porting framework is heavy angle iron. T
unit is equipped with automatic tempe
ture control, fused switch box, and st
down power transformer.—*K. H. Hupp
Co., 6830 Cottage Grove Ave., Chicago 37,*

Telephone System

A new two-way Sound Powered telepho
system equipped with convenient test clips
the cord tips facilitates tests on electri
installations. Communication is made p
sible without the aid of any external pow
supply or batteries, and the system is w
suited to testing pairs; sorting cabl
installing; checking; testing for short
cuits; identifying grounds; and other t
purposes. A pair of these lightweight a
waterproof handsets may be used
emergency communication over lines
carrying power, or over temporary fi
lines.—*United States Instrument Cor
Summit, N. J.*

Attenuators

A new line of attenuators, which featu
a special switching mechanism to trans
attenuator input to a pair of separate o
put terminals for cuing purposes, facilita
program switching and fading in "on cu
without increasing size of equipment. A
standard Shallcross ladder, bridged
straight T, or potentiometer can be equipp
for cuing action, including units as small
1¾ in. diameter. Besides its value as a spa
saver, the cuing attenuator contributes
improved program handling.—*Shallcr
Manufacturing Co., Collingsdale, Pa.*

Cable Clamps

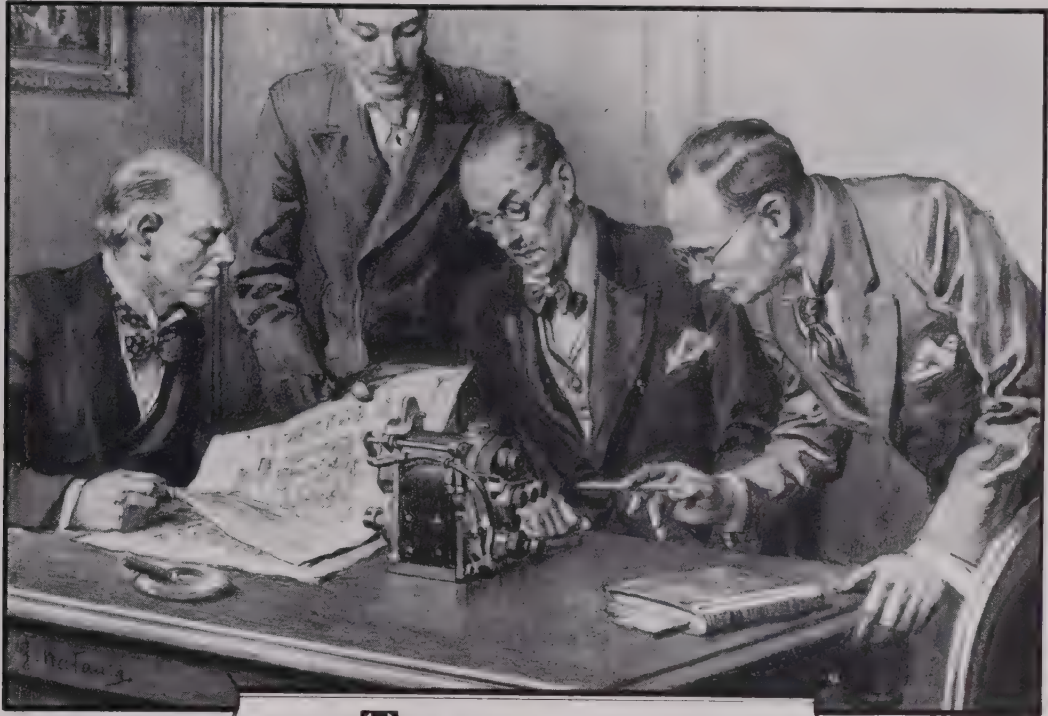
New cable clamps of strong, durab
black plastic have the characteristic of
dielectric, a new factor in cable clamps. T
is made possible by the use of plastic wh
affords protection from short-circuits res
ing from worn cables or wire covering. Ot
advantages include: lightness; ease of h
dling and installation, since only one scre
required; resistance to weather and fum
freedom from corrosion; and long servi
—*American Molded Products Co., 1644
Honore St., Chicago 22, Ill.*

Gear Tester

The 9-in. Parkson gear tester has be
redesigned to make for more efficient ope
tion of the machine, as well as streamlini
the base and other main parts. One impro
ment is the addition of the adjustable st
rod to the precision scale and long verni
that are used for setting the center distan
The stop-rod eliminates the need to rep
the scale setting when a number of gears
the same size are to be tested, thus speed
up the operation in repetitive tests. T
machine is available for spiral, spur, bev
and worm-gears, either in combination
single-purpose models.—*George Scherr
200 Lafayette St., New York 12, N. Y.*

(Continued on next left-hand pa

SIXTY YEARS OF PROGRESS



THE FIRST WORLD WAR

WHEN war broke out in 1914 The British Thomson-Houston Co. Ltd., turned their attention to the needs of the Services.

BTH were early entrusted with the design and manufacture of magnetos for aircraft and automobiles, hitherto virtually a German monopoly. Many thousands of these were supplied to the fighting services. In addition to electrical products the factories were employed in making such things as shells of various sizes, many parts for guns, tanks submarines, battleships and cruisers, depth charges, mines and many other fittings.

Although occupied on war work, BTH were no less assiduous in their pursuit of new ways and improved methods to benefit the peace. In 1915 BTH produced the first of its all-metal-clad switchgear, rated at 250,000 kVA at 11,000 volts.

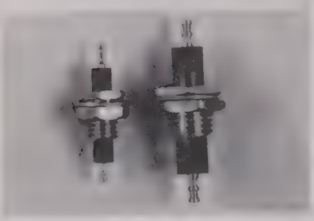
In 1916 experiments were begun on plastic products and in the manufacture of high-speed motors for spinning rayon filament. Many thousands of these motors were produced, with speeds from 6,000 to 9,000 r.p.m. Intensive development was also taking place in the production of turbo-electric propulsion for marine work. In addition continuous improvements were being made in the now world-famous Mazda Lamp. This spirit of progressive research and development is alive in the Company to-day and finds recognition in the respect accorded to the Company's name and products in all parts of the world.

BTH **RUGBY**

I.A.114

THE BRITISH THOMSON-HOUSTON COMPANY LIMITED, RUGBY, ENGLAND

Terminals



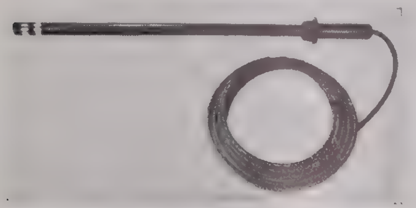
Insulated feed-through terminals designed for feeding high voltages through chassis, panels, cavity walls, etc. The insulating material is a phenolic having good dielectric properties. Metal parts are heavily plated, and the units are constructed to withstand shock and vibration. The terminals are available for ¼-in. or ⅜-in. hole mounting, each type in two lengths. The larger of the two ⅜-in. models, which is shown at the right, will withstand a breakdown voltage of 8000 volts, 60 cycles a-c.—*Cambridge Thermionic Corp., Dept. 8, 445 Concord Ave., Cambridge 38, Mass.*

Voltage Tester

A new voltage tester for testing continuity of circuits 110 to 550 volts a-c; 110 to 600 volts d-c; blown fuses; grounded side of line, motor, or appliance; excessive leakage to ground; 25- or 60 cycle frequency; and d-c polarity. Indications are by a solenoid indicator and a neon test lamp. This gives double protection, since each operates independently of the other. Securely anchored leads two feet long are brought out through top of case for ease of reading and handling.—*Ideal Industries, Inc., 1642 Park Ave., Sycamore, Ill.*

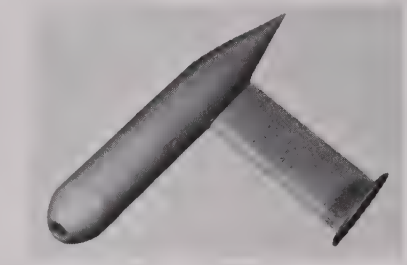
Conductivity Cell

A wand-type conductivity cell, Type VO-1, to use as a dip cell or to permanently mount in place. The device has a sturdy body of acid-resistant plastic, with handle at one end and flush electrodes of bright platinum at the other. Electrical connections are made by means of the 15-ft heavy neoprene cable with spade-lug terminals. This type of construction is especially useful where the liquid under measurement is viscous, or where there is a strong tendency for solids to deposit and coat the electrodes.—*Industrial Instruments, Inc., 17 Pollock Ave., Jersey City 5, N. J.*



Temperature Probe

Temperature probe, Type 4915, designed for aviation flight-test purposes, is used with temperature recording and transmitting devices in guided missiles, radio-controlled planes, and other test-aircraft in the speed ranges above 400 mph. The probe simplifies data calculation by measuring the total air temperature (ambient plus 100 per cent of the temperature rise due to velocity). Also, total time to complete a flight test is reduced, since the test-aircraft does not slow down for temperature readings. Two major improvements eliminate position errors and other inaccuracies: (1) all the velocity energy is converted to temperature; and (2) the instrument readings are protected against conduction losses and radiation inaccuracies by proper shielding design.



The probe is about six inches long and one inch in diameter, and it can be boom- or strut-mounted. When the unit is in operation, air enters the nose of the probe and flows around a resistance bulb, or thermocouple.—*G. M. Giannini & Co., Inc., 285 W. Colorado St., Pasadena 1, Calif.*

Terminal Board

A new one-piece low-loss molded terminal board incorporates insert-type heavy-duty tinned-brass lugs. The possibility of the terminals rotating is eliminated by this new design. The terminal board is molded to fit the contour of the attenuator, combining functional and design advantages. The insulation conforms to JAN specifications.—*The Daven Co., 191 Central Ave., Newark, N. J.*

Steel Hinge

A new type of steel hinge incorporates a spring clip to provide snap action to the lids of plastics packages. The device has teeth that bite into slots molded in both the cover and base of the package. This feature simplifies assembling operations, eliminating the use of screws and rivets, and consequently reduces manufacturing costs. The hinge can be used in both thermosetting and thermoplastic materials. Because all the spring tension is concentrated on the metal itself rather than on the box cover and base, the strain on the plastic is relieved, providing a stronger assembly.—*General Electric Company, Plastics Division, Pittsfield, Mass.*

Capacitor

A new high-Q capacitor designed f
radio, television, hearing aids, and oth
applications where leakage resistance a
moisture resistance are important facto
These condensers have a leakage resistan
of better than 5×10^{5} megohms, a pow
factor of 0.01 per cent, and they are prac
cally unaffected by humidity conditions. T
capacity range is 5 $\mu\mu$f to 100,000 $\mu\mu$f
voltages of 500 to 10,000 volts.—*Dum*
Electric Corp., 34 Hubert St., New York, N.

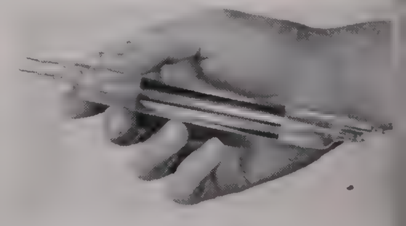
Heavy-duty Jacks

Two new heavy-duty hydraulic jac
the 30-ton FB-11 and the 50-ton GB-
combine the load pump and speed pu
into one unit. The load pump cuts
automatically when the speed pump

raised the saddle to the load. Both mod
have bases machined from steel blocks 2
in. thick, to withstand extreme stre
In addition to being one-man-operat
these jacks have a recessed safety rele
valve; over-all closed construction; po
for gage or valve installation; pump-be
protection; and on-the-side operation
Blackhawk Mfg. Co., Milwaukee 1, Wis.

Counter

A new Geiger-Mueller counter, Mo
D11, for use with recording instrume
All glass, with a window thickness of
milligrams per sq cm, the counter has
over-all dimensions of 8 in. by ¾ in., w
an active length of 3 in. Cathode mate
may be specified as copper or silver, and
central wire is made of 0.004-in. polish
tungsten.



A glass skirt at each end of the cen
wire insures a long flat plateau of appr
mately 250 volts, at a slope of only 2
cent per 100 volts. Threshold voltage for
tube is 850 to 950 volts, and expected
is 10^{6} counts.—*Instrument Developm*
Laboratories, 223 W. Erie St., Chicago 10,

TRADE LITERATURE

ilter—The operation and application self-cleaning air filter for engine and ressor service is given in this two-color hlet. Well illustrated with installation graphs, the pamphlet includes the sub- of operating principle, panel design udge removal. A dimension drawing of ised unit is provided, along with a ity and dimension table for computing capacity and weight. Eight pages. Bul- No. 150-100H-11-47-C.—*American Air Company, Inc., Louisville, Ky.*

ry Charger—Functionally labelled graphs illustrate this adjustable, self- ating electronic battery charger and ght construction features. The theory eration is explained, and a circuit dia- and charging-current vs. terminal ge curves are given. Four pages. Bul- GEA-3179C.—*Apparatus Dept., Gen- Electric Co., Schenectady, N. Y.*

citors—For electronic and service re- ment applications, this catalog is illus- l with detail drawings and halftones of than 20 different classes of capacitors. type is described as to construction service. Twenty-four pages. Catalog —*Cornell-Dubilier Electric Corporation, Plainfield, New Jersey.*

als—A listing of quartz crystals for nercial applications is given in this et. Cross-section diagrams and photo- s accompany each type listed, along text material that points out design res and applications. Ten pages. Bliley tin 36.—*Bliley Electric Co., Erie, Pa.*

Electrical Steels—Physical and mechanical features of these oriented steels are contained, with such magnetic qualities as core loss, exciting volt-amperes, and exciting ampere-turns given in chart form. Procedures are listed for the stress-relieving anneal, and a brief consideration is given to core design. Fourteen pages. Entitled "Oriented Electrical Steels."—*The American Rolling Mill Company, 703 Curtiss Street, Middletown, Ohio.*

Heavy-duty Resistors—Various types of ribbon resistors available for high-current applications are described. Resistance values, current-carrying capacities, dimensions, and method of mounting are some of the data given in conjunction with photographs, tables, and drawings. Eight pages. Bulletin 35.—*Ward Leonard-Electric Co., 31 South Street, Mount Vernon, N. Y.*

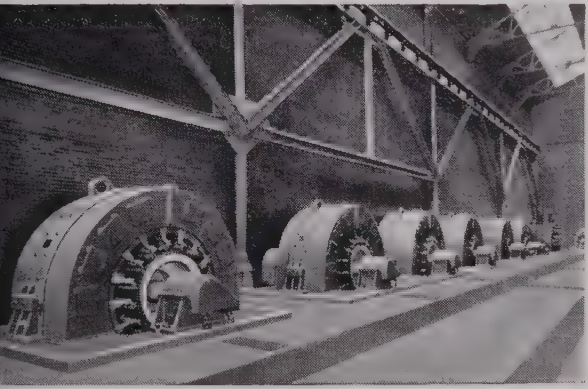
Printing Recorder—Power-plant supervisory system for both public utility and industrial power plants is described. Wiring diagrams are shown, and a schematic diagram of a typical layout illustrates the simplicity of the system. Sixteen pages. Entitled "Power Plant Supervisory System."—*The Autocall Company, 4747 Tucker Ave., Shelby, Ohio.*

Pyranol Capacitors—Capacitors for power-factor improvement and for the suppression of radio interference in fluorescent-lamp installations are the subject of this pamphlet. Dimension tables, cross-section diagrams, circuit diagrams, and voltage-rating tables are used to illustrate the application of these two types. Photographs of the capacitors for radio-interference suppression are also included. Four pages. Bulletin GEA-2526B.—*Apparatus Dept., General Electric Co., Schenectady, N. Y.*

Renewable Fuses—Significance of balanced lag in electrical fuses to combat unnecessary blows and resultant wastefulness of time. A construction diagram of the fuse indicates points of blow from sustained heat from overloads and from shorts, grounds, or sudden dangerous surges. Four pages. Entitled "Balanced Lag is Clicking."—*Pierce Renewable Fuses, Inc., 211-219 Hertle Ave., Buffalo, N. Y.*

Tantalum—Of interest to both the serious technician and to the lay reader, this well illustrated booklet tabulates the physical, chemical, and electrical properties of the metal, and in many instances, comparisons with better-known metals are made. Twenty pages. Entitled "The Metal Tantalum."—*Fansteel Metallurgical Corporation, North Chicago, Ill.*

Vibration-measuring Equipment—The dial-type vibration indicator, the light-beam type, and the vibration-velocity meter are described in this folder. Tables, general specifications, circuit diagrams, descriptive text, and illustrations comprise the contents. Eight pages. Bulletin GEA-4140A.—*Apparatus Dept., General Electric Co., Schenectady, N. Y.*



3500 hp and one 3000 hp D-C Motors manufactured at the Peterborough s of Canadian General Electric driving main rolls on a 56 inch continuous mill at The Steel Co. of Canada Ltd., Hamilton, Ont.

n *Canada* . . .

eight large factories manufacture General Electric products. 30 engineering and sales offices, and 15 warehouses are located from coast-to-coast to serve you.

NADIAN GENERAL ELECTRIC CO LTD

St. John • Sydney • Montreal • Quebec • Sherbrooke • Chicoutimi • Trois Rivières • Ottawa • Toronto
London • Windsor • New Liskeard • Sudbury • St. Catharines • Noranda • Timmins • Winnipeg • Fort William
• Regina • Brandon • Calgary • Edmonton • Lethbridge • Vancouver • Victoria • Trail • Kelowna

ELECTRITE

A high grade fibre board for electrical insulation. A material of quality possessing high tensile and dielectric strength. Used by many of the leading manufacturers of electrical equipment.

DENSITE

An extremely hard board of superior quality which can replace the more expensive types of insulating materials.

Pulp Products Department

WEST VIRGINIA PULP & PAPER COMPANY

230 Park Avenue, New York, N.Y. 35 E. Wacker Drive, Chicago, Ill.

BOOK REVIEWS

(Available books may be purchased through the GENERAL ELECTRIC REVIEW for domestic delivery; none sent on approval.)

Fundamentals of Electricity and Magnetism. (Third Edition)

Leonard B. Loeb—669 pp. 1947. John Wiley & Sons, Inc., New York. $6.00.

This book is a University of California class-room development of the subject for a four-credit first-semester sophomore class of engineering, physics, and chemistry students. It must be a full course, for the treatment is on a high level and of broad coverage. The approach is unobtrusively historical, with healthy emphasis on the empirical basis of our knowledge.

The "classical" parts of the subject are covered thoroughly and well with a careful and conscientious development of fundamental concepts. The relation between laboratory and classroom is continually recognized in the text and is implemented by tabulations of methods of measurement. The treatment of electrolysis and ionic conduction is excellent.

Beyond the "classical," a considerable portion of the text is devoted to the topics: relativity—a statement of its bare elements; gaseous conduction, atomic and nuclear constitution of matter including quantum numbers and the Pauli exclusion principle to the extent of thirty-three pages; x-rays; high-energy accelerators—very up-to-date; and klystrons and magnetrons. A notable feature is that wherever quantum theoretical considerations apply to a phenomenon, they are used in describing it, notably in ferromagnetism, Peltier Effect, and thermionic and photoelectric effects. Missing is a table of conversion factors to the MKS system. Present are some 350 problems, with answers, covering all phases of the subject. There is a sparse scattering of errors and a few misleading phrasings (which one can always find)—none of them important. The book is an excellent one for the purpose for which it is intended.

Lewi Tonks

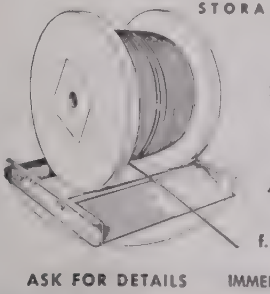
TO REEL OR UNREEL
THE EASIEST WAY

WHATEVER YOU USE ON A REEL . . .
WIRE, CABLE OR ROPE. SAVE TIME AND LABOR WITH

ROLL-A-REEL

Portable
Lightweight
Slanted front
Positive front lock
No jacks needed
Adjustable slots for many widths

TAKE IT TO REEL,
STORAGE OR JOB



Style A:
2,000 lbs. cap.
37.50

Style B:
4,000 lbs. cap.
75.00
f. o. b. Cincinnati

ASK FOR DETAILS   IMMEDIATE DELIVERY

ROLL-A-REEL
327 WEST FOURTH STREET
CINCINNATI 2, OHIO

Laboratory Exercises in Inorganic Chemistry.

W. Norton Jones, Jr.—315 pp, 8 x 11 in. 1947. Blakiston Co., Philadelphia. $4.50.

This well-designed laboratory manual consists of instructions, problems, and report forms for 50 exercises in introductory college-grade chemistry. The exercises deal not only with the representative elements and their chemical behavior, but also with laboratory techniques and a considerable part of elementary physical chemistry in simplified form. In this respect, the course so outlined is more general than inorganic.

Like most professors, Dr. Jones undertakes his task with highly optimistic aims: "the acquisition of a firsthand knowledge of . . . chemical substances, the learning of proper laboratory techniques, the development of the scientific method . . . , the development of a deeper insight into chemistry . . ." Certainly any one of these aims, thoroughly done, would be a major accomplishment in a freshman course. It might also be thought that the experiments on cryoscopic determination of molecular weight, Graham's Law and the diffusion of gases, and equilibrium and the rate of reaction, though well done, are above the heads of the students who will use the manual. However, this undoubtedly is better than aiming the course too low.

The pull-out pages bearing indexed questions on the experiments are handled very well, but will require about half the laboratory time to complete. Perhaps it may also be right for the students to spend half of their time thinking about what they have done. Some of the tasting experiments might seriously be questioned, however, and also the practice of snapping glass tubing upward toward the face (and without safety goggles!). Undoubtedly these, safely past, will contribute to the "deeper insight into chemistry."

E. G. Rochow

The Chemistry of Carbon Compounds, Volume IV. (Third English Edition; based on Twelfth German Edition)

Victor von Richter (Edited by Richard Anschütz)—498 pp. 1947. Elsevier Publishing Co., New York. $12.00.

Volume IV completes the English translation of the twelfth German edition of this classic treatise on organic chemistry. Part I (387 pages)—*The Heterocyclic Compounds*, by F. Reindel—is a survey of the available descriptive chemistry up to about 1930 in this rapidly advancing field.

The new edition represents an extension of about eight years in time and one-third in size beyond the previous edition.

Part II (70 pages)—*The Organic Free Radicals*, by Ludwig Anschütz—is a digest of the descriptive literature up to 1935 regarding the so-called stable organic free radicals—that is, those having more than a transitory existence as reaction intermediates.

Written in the style of Beilstein, the book is a comprehensive, orderly, and concise compilation of specific experime facts, the physical interpretation of w is beyond its scope. It is undoubtedl great importance as an advanced text reference work, and its value is enhar by generous reference to the original lit ture.

R. H. Krie

Elementary Nuclear Theory.

H. A. Bethe—147 pp. 1947. John Wile Sons, Inc., New York. $2.50.

Among the distinguished consultants the nucleonics project of the Gen Electric Research Laboratory is Dr. H A. Bethe, Professor of Physics at Cor University and formerly head of the t retical physics division in the Atomic B Laboratory at Los Alamos (N. M.). In summer of 1946 Dr. Bethe presente series of lectures in the G-E laborator acquaint the Company's scientists engineers with some of the basic dat nuclear theory.

Careful notes were taken and distrib to those who attended, but the demand them far exceeded the supply. They bec the basis of the present book, which pres a concise survey of certain selected to These are, for example, the descrip theory of nuclei of atoms, the qualita theory of nuclear forces, beta disintegrat and the compound nucleus. Most of material has been available previously, all, only in the technical journals.

Dr. Bethe's book is the first in a series of advanced works on various asp of nuclear science. Others will deal cosmic rays, medical and biological appl tions of radioactive tracers, neutron phys the separation of isotopes, radiation tection, etc.

James Stok

Electronic Engineering Patent Index.

Edited by Frank A. Petraglia—476 1947. Electronics Research Publishing New York. $14.50.

This book is a compilation of exce from electronic patents issued in 1 taken from the Official Gazette of United States Patent Office. The exce are grouped in ninety-three classes, acc ing to subject matter, with the titles of classes listed in an index of contents. classes do not follow the official classi tion of the patent office but form a q satisfactory subject-matter division of part in question.

The book should be useful to a searc particularly by reason of this subj matter index. For example, one class li in the index is Frequency Responsive cuits and Devices. On looking at the cerpts in this class, one finds patents f official classes 250 sub 40, 171 sub 119, sub 281, 171 sub 327, 250 sub 36, 171 97, 178 sub 5.6, and others. These exce may then be used as a quick basis for de mining a field for search.

Probably, however, like most such dexes, the book cannot be depended u entirely. For example, one class listed in index is Radar and Radio Ranging Syste On looking at the excerpts here, one f patents from numerous official classes subclasses; but none is included from 250 sub 1, where patents directed to r and ranging systems are frequently pla

(Continued on next left-hand p

Getting Load and Voltage Facts IN A HURRY!

YPE AK-1

OOK-ON VOLT-AMMETER

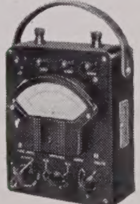
To keep plant operation at peak efficiency and spot trouble before it causes tly breakdowns, constant testing with reliable instruments is a "must." re you'll find the General Electric hook-on volt-ammeter one of the handiest d most versatile instruments you've ever used, for it permits quick measure- nt of both volts and amps.

NSTRUMENTS IN ONE

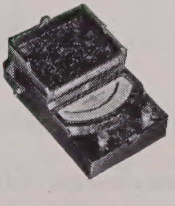
The reason the AK-1 hook-on volt-ammeter is so handy is that it's really six truments in one. It has six ranges: 0-15/60/150/600 amp and 0-150/600 lts (for a-c circuits only). To measure amperes, all you do is hook it around a nductor, flick the selector switch to AMPERES, and there's your measure- nt—no cutting of conductors, no lost service. To measure volts, all you do onnect the voltage leads, snap the switch to VOLTS, and take the reading— extra equipment needed.

Extension poles, in four- and six-foot lengths, are available for using the -1 on high-voltage circuits, and for reaching into inaccessible places. Also, a hide leather carrying case can be obtained for protecting the instrument en it is not in use. For further information, contact your local distributor or ur nearest G-E sales office. Write for Bulletin GEA-2950, *Apparatus Dept., neral Electric Company, Schenectady 5, N. Y.*

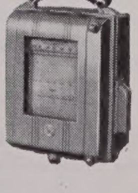
Which of these Testing Instruments do you lack?



AF-1
A-C LOAD
VISUALIZER



AP-9
A-C VOLT-
METERS and
AMMETERS



CF INKLESS
RECORDER

GAUSS
METER

GENERAL ELECTRIC

602-111

BOOK REVIEWS (Continued)

Probably this incompleteness would be reduced, and the general utility of the book increased, if excerpts for more than one year could be included in the volume; but it is unlikely that successive purchases of individual yearly volumes would be justified.

M. D. Morse

Electronic Transformers and Circuits.

Reuben Lee—282 pp. 1947. John Wiley & Sons, Inc., New York. $4.50.

This book should help fill a long-felt need. The preface states, "The purpose of this book is twofold: first, to provide a reference book on the design of transformers for electronic apparatus and, second, to furnish electronic equipment engineers with an understanding of the effects of transformer characteristics on electronic circuits."

To accomplish this purpose the author shows in a clear manner the relations between the transformer parameters and their performance characteristics in a wide variety of electronic circuits. The equivalent circuit of the transformer is shown to be of such a form as to permit its performance in the electronic circuit to be readily calculable by filter principles familiar to electronic equipment engineers. Sufficient description of the fundamentals of the various electronic circuits are given to enable the designing engineer to appreciate the effect of the associated circuits upon his transformer design.

The book includes transformer-design and circuit-performance data for several types of rectifier circuits; a-f, i-f, and r-f transformer-coupled amplifiers; push-pull modulation transformers; pulse, blocking oscillator, and saw-tooth transformers; grid control, peaking, and current-limiting transformers; reactors with d-c current components and saturable reactors. Examples of designs are given for most of these and each chapter concludes with several illustrative problems.

H. W. Lord

High Vacua.

Swami Jnanananda—310 pp. 1947. D. Van Nostrand Co., Inc., New York. $5.50.

This book fills a need for an up-to-date discussion of the methods of producing and measuring high vacua. About one fourth of the book is devoted to kinetic theory, including a description of the flow of gas through tubes. Sections dealing with pumps and devices for measurement of pressure occupy together about one half of the book. The remainder is devoted to the technique and production of high vacua and, while informative for a novice, would be of relatively little use to one experienced in the art.

A somewhat more critical treatment of the various devices described would be desirable. Many pumps and gages are included which are of more historical interest than practical importance. Only one reference later than 1921 is given in the section on occlusion of gases in metals, although considerable work has been done in this field since then. It is also surprising to find no mention of the use of the mass spectrograph and ion gages in the section on leak detection. No mention is made of thermocouple gages or thermistors for pressure measurement.

In general, however, the treatment is thorough and the book can be recommended to anyone interested in the production of high vacua.

L. R. Koller

Industrial Management. (Fourth Edi

Spriegel and Landsburgh (Revised by
liam R. Spriegel)—656 pp. 1947. John W
& Sons, Inc., New York. $5.00.

This is a good textbook. Fortunatel
limits the emphasis to the life and prob
within the factory property line. It t
only lightly sales and purchasing. It a
treatment of the initial promotion of
business, financing, and accounting. It
siders the organization, the plant,
study, and the various methods of
payment; the relations of labor and ma
ment, production control, and some o
techniques of managerial control. A re
is impressed again by the teeming com
ity of modern industry.

The choice of material is, in general, g
The scope is broad, but it is not enc
pedic. That would be asking too m
Many of the problems of industrial ma
ment and the most effective solutions
compromises found to the present tim
described. Although one may wish f
change of emphasis or interpretatio
various points, there is displayed a fine
sympathetic understanding of the indus
scene as it exists today.

At best, treatment of this subject in
lege is difficult. It is not easy to tran
such knowledge to students whose
quaintance with complex organizations
factory operations is often limited to q
tours of nearby industries and a desul
reading of a sometimes misleading p
press. But this book will be a great h

Perhaps the greatest immediate ben
can be obtained by those who have de
to spend their lives in industry and
have spent a few years there. Their
observations need integration and a s
ment of purpose. This textbook will
them to that goal.

W. W. Ku

ASSOCIATED ELECTRICAL INDUSTRIES LIMITED

British Thomson-Houston Co. Ltd.

Edison-Swan Electric Co. Ltd.

Ferguson, Pailin Limited

Harcourts Limited

Hotpoint Electric Appliance Co. Ltd.
(Incorporating International Refrigerator Co. Ltd. and Premier Electric Heaters Ltd.)

Metropolitan-Vickers Electrical Co. Ltd.

Metropolitan-Vickers-G R S Ltd.

●

Agents and Licensees of the
GENERAL ELECTRIC Co., U.S.A.
for the United Kingdom.

Your Own Copy

ON picking up a magazine, nothing is more disturbing than to find that an important article has been clipped out.

Because of the permanently useful information in the REVIEW, many of its articles are clipped out so that this material can be conveniently available for whatever the purpose may be.

In order that you may have your own copy of the REVIEW, complete and without delay each month, we suggest you subscribe now!

GENERAL ELECTRIC
REVIEW

SCHENECTADY 5, N. Y., U.S.A.

SUBSCRIPTION RATES: One Year, $3.50
Two Years, $5.50

Extra Postage (1 or 2 yr.)—Canada, 25¢; Foreign, 50

LIBRARY NOTES

ON ARTICLES IN OTHER TECHNICAL JOURNALS

NDITIONING

Help to Solve Lighting Problems.

Ira Franks—*Heat. Piping & Air* Sept., 1947; v. 19, pp. 103-105.
determining the load imposed on air ioning equipment as the result of heat ting from lighting installations.

NES

Aircraft and Carrier Equipment.

ldington—*Roy. Aero. Soc. Jour.*, Oct., v. 51, pp. 800-831.
the launching and landing of carrier- aircraft.

Icing of Highly Electrified Aircraft.

Gunn—*Jour. Aero. Sci.*, Sept., 1947; pp. 527-528.
rt account of tests which seem to show lectrical effects are not important in g deposition of ice on aircraft.

IERS

ic Amplifier Circuits, Neutral Type.

S. Fitzgerald—*Franklin Inst. Jour.*, 947; v. 244, pp. 249-265.
circuits described refer to magnetic iers of the neutral type, their response ndent of the polarity of the d-c input.

CING

Balancing of Large Rotors.

King—*Allis-Chalmers Elec. Rev.*, 1947; v. 12, pp. 8-11.
ation caused by uneven rotor heating isolated and corrected. Methods re the first to be published anywhere.

DE RAYS AND TUBES

-ray Presentation of Three-dimensional Data.

H. Schmitt—*Jour. App. Physics*, 1947; v. 18. pp. 819-829.
le transformations, which are easily ned electrically, make it possible to three-variable electrical data in the f isometric or other conventional ions or as true perspective drawings.

C HEATING

Industrial Electronic Generators.

Whiteman—*Radio-Electronic Engng.*, 1947; v. 9, pp. 8-10, 25.
methods for avoiding excessive ence to radio facilities from indus- dio-frequency generators.

C MOTORS

tion of Axial Air-gap Motor.

Pl. Engng., Sept., 1947; v. 51, pp. 8.
s of rotor and stator made in disk punched-strip magnetic steel. Rotor is of centrifugally cast copper, winding of wire, machine wound in slots.

N TUBES

-wave Tube.

pfner—*Wireless Engr.*, Sept., 1947; p. 255-266.
retical article on its use as a centi- vave amplifier.

BINES

l Turbine, Especially with Regard to Gaseous s.

T. Von Der Nuell—*Tech. Data* Sept. 1, 1947; v. 12, pp. 5-31.
eoretical paper on radial turbines ward and with outward flow.

HEAT INSULATION

Estimating Magnesia Insulation Costs.

Frederick C. Otto—*Chem. Engng.*, Sept., 1947; v. 54, pp. 126-129, 133.
Explains how and when magnesia can be used with economy as an insulating material in a plant.

HEAT TRANSFER

Heat Transmission from Fine Wires to Water; Low-velocity Data and Correlation.

Edgar L. Piret and others—*Ind. & Engng. Chem.*, Sept., 1947; v. 39, pp. 1098-1103.
Presents heat-transfer data obtained on fine platinum and nickel wires at water velocities lower than previously reported and for a relatively wide range of water temperatures and temperature differences. For use in connection with fluid-flow problems.

HEATING, RADIANT

Panel Heating; Open System vs. Closed System.

C. O. Mackey—*Heat. & Vent.*, Sept., 1947; v. 44, pp. 90-96.
A theory and procedure in open warm-air panel-heating design is presented and compared to closed-panel systems.

INSULATION

Microwave Dielectric Measurements.

T. W. Dakin and C. N. Works—*Jour. App. Physics*, Sept., 1947; v. 18, pp. 789-796.
An instrument and method for measuring the dielectric properties of solids at microwave frequencies. Makes use of a rectangular wave guide.

IRON AND STEEL

Mobile Laboratory Speeds Steel Analysis.

H. A. Tuttle and G. A. Nahstoll—*Iron Age*, Sept. 25, 1947; v. 160, pp. 68-72.
Describes truck-mounted spectographic equipment for on-the-spot inspection and testing of steels at Ford's River Rouge plant.

JIGS AND FIXTURES

Fixtures Make Rotary Surface Grinders Automatic.

Fred C. Schaub—*Am. Mach.*, Sept. 25, 1947; v. 91, pp. 69-73.
Grinding to half a thousandth can be done on a continuous production basis by proper design of work-holding devices. Typical arrangements are shown.

LUBRICATION AND LUBRICANTS

Oil Reclamation System Paid for Itself the First Year.

Herbert G. Knell and E. R. Keast—*Factory Man. & Maint.*, Sept., 1947; v. 105, pp. 78-81.
Plan used by the Wright Aeronautical Corp.

MACHINE SHOP PRACTICE

Investigation of the Lapping Process.

F. Eugène—*Engrs. Digest.*, Sept., 1947; v. 4, pp. 403-408.
Abstract translation from "Travaux et Memoirs du Laboratoire Central des Industries Mécaniques," 1945; v. 2, pp. 9-33.

MEASURING INSTRUMENTS—IONIZATION

On the Rise of the Wire-potential in Counters.

S. A. Korff—*Phys. Rev.*, Sept. 15, 1947; v. 72, pp. 477-481.
The rate at which the potential of the central wire in a counter changes when a count takes place is considered.

METALS

Clad Steels.

Mat. & Methods, Sept., 1947; v. 26, pp. 97-108.
Presents the basic facts about clad steels, the materials involved, fabricating and finishing information, and a comprehensive list of fields and applications.

STANDARDS

Reducing Material Costs Through Standardization.

H. R. Clauser—*Mat. & Methods*, Sept., 1947; v. 26, pp. 63-67.
In many plants material inventories have grown like Topsy until untold varieties and shapes are kept in stock. Establishment of plant standards in sizes and shapes can save considerable time, space, and money.

TELEVISION

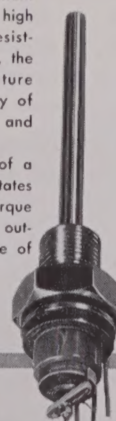
New Television Projection System.

William E. Bradley and Ernest Traub—*Electronics*, Sept., 1947; v. 20, pp. 84-89.
Combination of a Schmidt optical system, a new phosphor, directional viewing screen, keystone projection, and ingenious cabinet arrangement produces a 15- by 20-in. picture of exceptional brightness and contrast.

VIBRATIONS

Vertical Vibration of Ships.

C. W. Prohaska—*Shipbldr. & Mar. Engine-Bldr.*, Oct., 1947; v. 54, pp. 542-546.
Its determination and its relation to the speeds of main engines and propellers.



TEMPERATURE TRANSDUCER
from −65°c to +150°c

Latest type Giannini Temperature Transducer combines excellent range, large outputs and high accuracy. Available in resistances up to 20,000 ohms, the new type 4911 Temperature Transducer has a linearity of 1%, an accuracy of 1%, and a sensitivity of 1° C.

The instrument consists of a bi-metallic element that rotates a standard Giannini Microtorque Potentiometer for electrical outputs. This instrument is one of thirty basic Giannini developments in the telemetering field.

Write for complete engineering details.

GM Giannini & Co Inc
285 WEST COLORADO STREET, PASADENA 1, CALIFORNIA
OFFICES: NEW YORK, NEW YORK — DAYTON, OHIO

HOW TO
BE SURE
YOU GET
THE BEST
IN
Capacitors

You can

test the paper for density . . . thickness . . . porosity . . . power factor . . . chloride content . . . dielectric constant . . . dielectric strength.

And then test the foil for thickness . . . purity . . . softness of the anneal . . . freedom from oil . . . cleanliness of surface . . . absolute smoothness.

And then test the liquid dielectric for specific gravity . . . viscosity . . . power factor . . . color . . . acidity . . . flash point . . . dielectric strength . . . dielectric constant . . . insulation resistance . . . water content.

And after that, test every single finished capacitor for shorts, grounds, and opens at overvoltage between terminals and between terminals and case . . . and measure the capacitance of every single unit . . . and then check every single capacitor to see that it has an air-tight, leak-proof hermetic seal.

Or you can

buy General Electric capacitors... which have already passed every one of these tests

. . . on the materials when they were made.

. . . and again before they were used.

. . . and on the capacitors du
manufacture.

. . . and then, finally, on every s
capacitor before shipment.

SPECIALTY CAPACITORS

General Electric makes a wide
ety of specialty capacitors, a
which must pass similar compr
sive tests. For full informatio
types, ratings, dimensions, typ
mounting, and prices, addres
nearest General Electric Appa
Office or *Apparatus Departn*
General Electric Company, Sch
tady 5, N. Y.

GENERAL ELECTRI

Specialty Capacitors FOR

- Motors
- Luminous-tube transformers
- Fluorescent lamp ballasts
- Industrial control
- Radio filters
- Radar
- Electronic equipment
- Communication systems
- Capacitor discharge welding
- Flash photography
- Stroboscopic equipment
- Television
- Dust precipitators
- Radio interference suppression
- Impulse generators

AND MANY OTHER APPLICATIONS